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BRIDGE AND TUNNEL CENTRES.

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I.

In the construction of stone and brick arches, of whatever shape and span, and to whatever use applied, whether as supports for roadways or roofs of tunnels, there is nothing which requires more careful attention on the part of the constructing engineer, than the centres. Independent of the choice of material, of the exactness with which each stone is cut, and the care with which it is laid in place, the success of arches of great span, their settlement and ultimate stability depends essentially on the care given to the framing, setting up and striking of the centres. The slightest change in the shape of the frame caused by the shrinking of an ill-seasoned timber, or the yielding to compression of a badly proportioned brace, will assuredly be followed by a change in the curve of the intrados, which may possibly result in the ruin of the arch itself.

Well constructed centring, therefore, is indispensably necessary to a well constructed arch, and in the following papers it is our intention to offer a practical investigation of the principles which must be followed out in the planning and mechanical execution of all such centre frames; to determine what strains must be withstood, at what point they act with most vigor, and by what combination of beams and by what system of bracing, the greatest strength and stiffness may be combined with the utmost lightness and the strictest economy of material.

BRIDGE CENTRES.

Of all classes of centres, the most complicated in structure is, beyond doubt, that of a large span stone bridge. Like a roof frame, it consists of a number of vertical pieces, placed in the direction of the span, from 5 to 7 ft. from centre to centre, and known as the *ribs*, upon which are placed horizontal pieces or *laggings*, and on these latter rest the voussoirs till the key stone course is driven and the arch becomes self-supporting.

THE FRAME in its turn is composed of *back pieces*, or short beams cut on the outer edge to the same curve as the intrados of the arch, a horizontal *tie beam*, and a number of *struts*, *ties* and *braces*, the arrangement, number and dimensions of which, will depend on the shape and span of the arch, and the number and position of the points of support. Whatever may be the span and curve of the arch, and the points of support afforded, experience has amply proved that the ribs should be polygonal in shape, with short sides: this shape being given by forming the

back-pieces, on which rest the laggings, of two or more courses of planks, placed in the form of a polygon and firmly nailed together; the planks in each course abutting end to end by a joint in the direction of the radius of curvature of the arch, and breaking joints with those of the other course.

For light arches of moderate span, or indeed for heavy arches of wide span when firm intermediate points of support can be had between the abutments, the back pieces may be strengthened by struts or ties placed under them, well braced, and abutting against a horizontal tie beam. This beam spans the arch a little above the springing line, is bolted to the back-pieces at either side, thus preventing them from spreading laterally, and if well sustained by props from beneath, affords a firm support to the struts and braces of the rib. In by far the greater number of cases, however, where headway is required under the centring during the construction of the arch, as is the case with stone bridges spanning a river whose navigation cannot be impeded, or whose current is too swift and depth too great to give firm points of support to the props of the tie beam, it becomes necessary to do away with the latter, and supply its place by such an arrangement of beams as will transmit the strains received to points of support at the abutments. This latter class of centring is known as "*retroussée*" or "*cocket*," and requires a much more careful and elaborate arrangement of its parts than the former.

We have therefore two classes of bridge centres to deal with; one in which the frame is constructed without regard to headway beneath it, and is supported from firm points of support between the abutments, and one arranged to leave headway under the frame, and upheld by framed supports at the abutments.

Before attempting to determine the most advantageous arrangement of the pieces which must compose the frame, their number and the dimensions it is necessary to give them in order that they may offer a solid support to the arch stones, it is fitting to consider the effect of the load the ribs are expected to uphold, the strains it produces, the points where and the directions in which the strains act and their intensity.

THE STRAINS.

The strains to which centre frames are subjected arise solely from the pressure upon the back-pieces and laggings, due to the weight of the voussoirs laid upon them, and are therefore extremely variable, depending on the span and curve of the arch, and the thickness and weight per cubic foot of the voussoirs which press upon the centring. It is not, however, to be supposed that *all* the voussoirs from springing line to springing line *do* press upon the frames, this depending to a very great degree on the curve of the arch. If, for example, we take the case of a full centre arch and starting at the springing line on either side pass towards the crown, we shall find that for a considerable distance above the springing line the stones do not exert any pressure upon the ribs, but that, as soon as this point is passed, the pressure begins and increases rapidly, reaching its maximum intensity just before the keystone course is driven into place. When this is done the pressure is almost entirely removed, and were it not for the slowness of the mortar in drying, the frame work of the arch might be done away with.

And, here, I would mention that, although it is generally held that when the keying course is placed, the voussoirs, with the exception of a few courses at the crown, cease to press, I have found by the most careful experiments with large, well-framed models, that the thinnest Chinese paper when coated with black lead and placed under the blocks of arch stone, *could not* be *drawn out*, even when the arch was keyed, without considerable resistance.

Upon further examination it will be found that these voussoirs which lie near the springing line and exert no pressure upon the laggings and back-pieces, are all of them contained within the angle of repose; that is to say, the voussoirs do not begin to press upon the centring until we reach one whose lower joint makes so great an angle with the horizon, that the stone is caused to slide along its bed under the action of gravitation. This angle for full centre arches has been fixed at from 28° to 30°, but

the quality of the stone and mortar used, will cause it to vary greatly. For ordinary cut stone, we may with safety assume the angle of friction at 30° with the horizon: when laid in thin tempered mortar it is increased to 34° or 36°, and with very porous stone, such as freestone, laid in full mortar it will reach almost 45°.

It is to be observed, however, that this is not strictly true unless the arch is of sufficient thickness at bottom to prevent all tendency to upset inwards. A thickness of $\frac{1}{10}$ the radius of curvature is usually adopted as sufficient for this purpose.

Adopting 30° as the angle of repose for cut stone, the number of voussoirs which load the centre will depend on the curve given to the intrados. If we take, for instance, a full centre, an oval and a flat segmental arch, and give to each the same number of voussoirs, it is evident that the number of stones which do *not* press on the laggings will be greatest in the full centre, less in the oval, and least of all in the flat segmental arch, because in this latter case the stone whose lower joint makes an angle of 30° with the horizon will be found nearer the springing line. We should expect, therefore, the number and weight of the stones being the same, that the segmental arch could give the greatest load to the centres, and the full centre arch the least; and this is strictly the case.

In estimating the load upon the centres in any case, it is to be remembered that none of the stones bear upon the ribs with their entire weight, a part of this latter being consumed in overcoming friction. The determination of the amount of weight thus expended is a matter of some mathematical intricacy, and we are indebted for its solution to M. Couplet.* By his calculation he found that the total weight of the voussoirs which *do* press on the laggings, is to the weight with which they actually load the frame, as an arc of 60° is to twice its sine less the same angle; or, to express it algebraically, denote by P the total weight of the voussoirs which *rest* on the centring, and by p, the weight with which they *load* the centres, and we shall have the expression

$$P : p :: \text{arc } 60° : 2 \sin 60° - \text{arc } 60° \quad (1)$$

or

$$p = \frac{P\ (2 \sin 60° - \text{arc } 60°)}{\text{Arc } 60.} \quad (2)$$

If, therefore, we suppose the radius of a circle to be divided into 10,000 equal parts, the circumference will contain 62,832, and the arc of 60° 10,472, and its sine is equal to $\frac{1}{2}\sqrt{3}$,8660. Substituting these values in the above equation (1), we shall have

$$P : p :: 10472 : 2 \times 8660 - 10472 \quad \text{or}$$
$$P : p :: 10472 : 6848$$

which gives us a ratio of 3 to 2 very nearly. Whence we see that the voussoirs in a full centre arch which press upon the laggings will do so with but $\frac{2}{3}$ of their weight, and, taking the angle of repose on each side at 30°, only on $\frac{2}{3}$ of the surface of the centring. We may, therefore, without any sensible error take $\frac{4}{9}$ of the gross weight of the voussoirs of the arch to express the load on the centres.

With an arch which is not full centre the case is quite similar. We will take an oval of three centres fulfilling the conditions that each of the three arcs composing it shall be 60°. This oval being drawn, it is at once apparent that the arcs of 60° at each end of the oval do not differ materially from that of 30° in the full centre arch. We may, therefore, to facilitate calculation, safely assume that the stones forming these two arcs of 60° do not press on the centres, when the arch is all up except the keystone, and are held in place by the weight of the voussoirs above them. There remains then but the central arc of 60° to load the framing. But from equation (1) $P : p$ as the arc of 60° is to twice its chord less the arc of 60°; and since 60° is to its chord very nearly as 22 to 21, we may without sensible error express the relation of P to p by the ratio of 11 to 10. When we have found the gross weight of the voussoirs in this arc of 60° it follows that we must take $\frac{11}{21}$ of their weight to express the load on the framing.

The chord of an arc of 60° is equal to

* Mémoire de l'Académie Année, 1732.

the radius, and the radius in this case being 10000, the *chord* will equal 10000, and the *arc* of 60°, 10472. Hence we have the relation 10000 : 10472 :: 21 : 22 *nearly*.

These values may also be obtained from the integral calculus, in which case no regard is taken of friction, and the formulæ are therefore a little uncertain. This uncertainty, however, is on the side of safety, for when we leave out of consideration the pressure expended in overcoming friction we are forced to give the ribs and laggings unnecessary strength.

Referring to Figure 1, we wish to find the load which the voussoirs between A B C D give to the centre's rib.

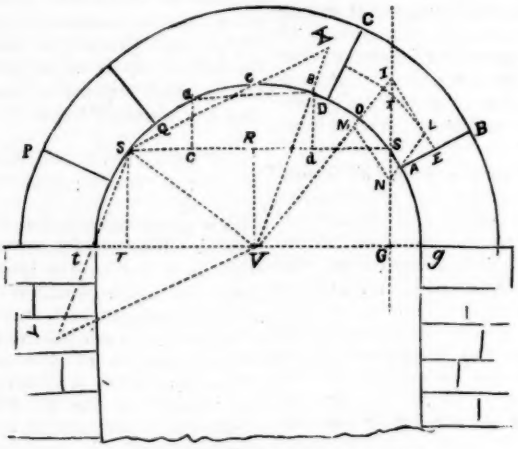

FIG. 1.

Let w equal the weight per lineal foot of intrados of the arch resting on the rib.

By x and y the horizontal and vertical co-ordinates respectively of the point A.

By x' and y' the co-ordinates of D.

By r the radius of the curve of intrados at A, and

By α the angle it makes with the horizon.

By P the gross vertical pressure on the rib of A B C D.

By p the pressure per lineal foot of intrados at A.

Then we shall have

$$P=\int_{x'}^{x} p\,dx \quad . \quad . \quad . \quad (3)$$

From this we may compute the load on any vertical post at this point, or the vertical component of the load on the back pieces.

If the arch had been completed up to the keystone course, equation (3) would have been

$$P'=\int_{o}^{x'} p\,dx \quad . \quad . \quad . \quad (4)$$

P' being the greatest vertical load on the *half* rib, and x' the horizontal distance from the middle of the span to a point where p is zero.

The value of p is found from the equation

$$p=W.\ \mathrm{Cos}\ \alpha-\frac{1}{r}\int_{y}^{y'} W.\,dy \quad . \quad (5)$$

which will evidently be greatest when

$$p=W.\ \mathrm{Cos}\ \alpha \quad . \quad . \quad . \quad . \quad (6)$$

When the arc is a segment of a circle not greater than 120°, we shall have from the relation between the sides and angles of a triangle, the following values of the co-ordinates :

$x=r\sin\alpha \quad x'=r\sin\alpha' \quad x''=r(\sin\alpha'')$

$y=r(1-\cos\alpha) \quad y'=r(1-\cos\alpha')$

Substituting these values in equation (5) we shall have

$$p=w(2\cos\alpha-\cos\alpha'). \quad . \quad . \quad (7)$$

And from the expression $y=r(1-\cos\alpha)$ we have

$$\text{Cos } \alpha = \frac{r-y}{r};$$

and from $y'=r(1-\cos\alpha')$

$$\text{Cos } \alpha' = \frac{r-y'}{r}$$

Substituting this in equation (7) we shall have

$$p = w\left(\frac{2r-2y}{r} - \frac{r-y'}{r}\right)$$

$$= w\,\frac{r-2y+y'}{r} \quad . \quad . \quad . \quad . \quad (8)$$

Equation (6) then becomes $p=w\cos\alpha$ $=w\frac{r-y}{r}$ the greatest value for a given point of the arch.

Substituting in equation (3) the value of p found in eq. (8), and, reducing, we obtain

$$P=wr[\alpha-\alpha'-\sin\alpha(\cos\alpha'-\cos\alpha)] \quad (9)$$

or

$$P=w\left(l-l'-\frac{x}{r}[y-y']\right)$$

in which l and l' represent the length in feet of the arcs from the crown E (Fig. 1) to the points A and D respectively.

Equation (4) then becomes

$$P'=wr(\alpha''-\sin\alpha''[1-\cos\alpha'']) \quad (10)$$

To find the gross weight of that portion of the arch which presses on the back pieces and laggings, it is necessary to know the number of the voussoirs, their volume and weight per cubic foot.

The weight of stone generally used in arches varies from 120 to 180 pounds per cubic foot. The following results were obtained from the examination of a number of specimens of American granite, sandstone and limestone, taken from the best known quarries in the country. Of seventy-two specimens of granite examined, the greatest weight per cubic foot was 182.5 lbs., the least 161.2, and the average 167.09 lbs. Of fifty-three specimens of sandstone examined, the greatest weight per cubic foot was 164.4 lbs, the least 127.5, and the average 140.9 lbs. Of thirty-eight specimens of limestone, the greatest weight per cubic foot was 173.8, the least 143.2, the average 162.9.

We may therefore without sensible error assume the average weight of these three classes of stone as follows:

	Average weight per cubic foot.
Granite	167.09 lbs.
Sandstone	140.9 lbs.
Limestone	162.9 lbs.
Brick (well burnt)	92.0 lbs.

From the moment the angle of repose is passed and the first voussoir begins to press on the frames, the centring becomes subjected to a series of strains which increase rapidly up to the time the keystone is laid, and are produced by the yielding of the ribs under the weight of the stones. No matter how well seasoned and admirably proportioned the timbers may be, or how evenly the load may be distributed, the centre, pressed more and more severely on each side by the successive courses of voussoirs laid upon it, will bend in on the sides, and as a consequence bulge out at the crown, to be in turn followed by a bending in of the crown when the arch is all but completed. This movement of the ribs can be greatly checked and the severity of the resulting strains much lessened by loading the centres at the crown with the spare voussoirs and increasing the load as the arch progresses. In the case of a full centre arch of 90 feet, and composed of four hundred and eighty courses of voussoirs, the centring, when the fifteenth course of voussoirs on each side were laid in place, had risen three inches at the crown. When loaded with 325,000 lbs., it settled under it two inches; but when the twentieth course was completed the pressure was so great that it again rose one inch. When the arch was three-quarters completed it had again sunk one inch and three-quarters in consequence of the additional load and the compression of the wood, still leaving a rise of one quarter of an inch. This yield caused the joints at the twenty-second course to open a fraction of an inch, but closed when the keystones were driven. This distortion of the centring is always greatest for full centre arches, and proportionally less as the arch becomes nearer and nearer to the segmental.

DIRECTION OF THE STRAINS.

To find the direction and intensity of

the strain at any point of the rib, we resort to the usual method of the "parallelogram of forces." Returning to Fig. 1, let it be required to find the direction of the strain caused by the voussoirs A B C D. Denote by F the centre of gravity of this part of the arch, and through it draw a vertical line G I of indefinite length, and cut it at I by a perpendicular from the point E at which the curve drawn through the centres of gravity of the voussoirs—supposed indefinitely small—cuts the line A B. Complete the parallelogram by drawing the line I M to the centre of arch, and N L parallel to it. The diagonal I N will then express the weight of the voussoirs A B C D, the side I L the pressure they exert upon the lower part of the arch, and the side I M the pressure upon the backpieces of the rib.

The strains, then, upon the centring take the direction of the radius of curvature of the intrados, and it now remains to consider the position which should be given to the beams which are to withstand the strains, their number and dimensions.

THE PRINCIPAL BEAMS AND THEIR POSITION.

As the sole object of the framing is to uphold the voussoirs and transmit the strains it receives as directly as possible to firm points of support, the beams must be so arranged as to do this with the least tendency to change the shape of the rib, by their bending or breaking. The condition will be best fulfilled by giving each beam a position such that it shall offer the greatest possible resistance, and this will be accomplished when the direction of the fibres of the beam and the direction of the strain are one and the same.

If, for instance, we support a horizontal beam at its two ends and load it in the middle it will offer its least resistance to the load. If now we raise one end so that the direction of the strain is oblique to the fibres of the beam, the resistance of the beam to bending will be found to have increased largely, and the resistance in this latter case, will be to that in the former case, as the cosine of the angle made by the direction of the strain and the fibres of the wood is to the sine of 90° or 1.

It should follow from this that, when the angle between the beam and the strain is zero, the resistance becomes infinite, and such would indeed be the case were it not for the compressibility of the wood and other physical causes which weakens its strength. It is sufficient, however, for us to know that when the strain is carried through the axis of the beam, it is then strongest, and that as the force becomes more and more oblique to the fibres its strength decreases.

Applying this fact to the framing of the ribs, it follows that the greatest stiffness and strength will be gained when the principal pieces are placed in the direction of the strains, or in the direction of the radii of curvature of the arch to be upheld. This deduction, unfortunately, is under certain restrictions placed upon it by the imperfections of the timber, and demands of economy and the circumstances of construction, which make its practical application quite limited.

To illustrate, we will once more return to Fig. 1. The direction and intensity of the strain on the backpieces resulting from the weight of the voussoirs ABCD, will then be represented, as we have just seen by the line V M, and that of the voussoirs P Q by the line V S. The beams, therefore, which are to support these stones, in order that they may offer the utmost resistance, must take the direction of the lines V S and V M, or radiate from the centre V like the spokes of a wheel. For small span arches, such an arrangement of beams undoubtedly answers all purposes of stiffness and economy, but for arches of larger span where timbers of thirty, fifty, or even a hundred feet in length would be required, it fails most signally; for while a beam of ten feet will offer great resistance to compression when loaded in the direction of the fibres, a beam of fifty feet will be almost sure to bend under the action of the strain, and hence require bracing. This system, therefore, cannot be successfully carried into practice in large span centres.

To overcome this difficulty we are forced to resolve the force represented by the line S V into two components, one vertical and represented by the line S T, and one horizontal represented in direction and intensity by S R. By a similar

treatment of the force represented by V M, we shall obtain two other similar lines, all four of which will represent the direction of three beams, which can be made to take the direction of the two V S and V M, namely, a long horizontal beam spanning the arch and supported at each end by a vertical beam. This horizontal beam is the *tie* beam to which we have already alluded, and is generally placed at points about 45° up the arch. The voussoirs above this beam are then supported by another horizontal tie upheld by small vertical beams abutting on the lower tie. An excellent illustration of this system of framing is found in centres of London Bridge over the Thames, built in 1831 by Rennie.

There will frequently arise cases in which ribs framed in this manner either on account of the quantity of material they consume, or the difficulty of finding firm points of support between the abutments, cannot be used to advantage. It then becomes necessary to change the point of support T of the beam S T (Fig. 1) to a point *t* nearer the abutment, and for the sake of economy we may do away with the horizontal and vertical beams *t g*, *s* S, T S, *c a* and *a b*, supplying their place by two beams *t* S and S *e*. These two beams, therefore, will sustain the strain represented by the line S V, and the efforts they resist will be represented in direction and intensity by the sides S X and S Y of the parallelogram X Y constructed on S V as a diagonal.

In "cocket" centres, therefore, whatever the span of the arch, whether large or small, whatever the shape, whether full centre, oval or segmental, a great saving of material may be made, and abundance of strength may be secured, by placing the principal beams in the direction of the chords of the curve of the intrados.

The length that should be given to beams thus placed, the angle they should make with each other at their point of junction, the manner of supporting, and when necessary bracing them, are points we shall reserve for future consideration.

There are, therefore, three methods of arranging the principal pieces or struts of a centre frame.

1°. They may be placed in the direction of the radii of curvature of the arch, thus giving a figure of invariable form as the strain at any one point is received by the beam in the most favorable position, and transmitted through its axis directly to the fixed point of support.

2°. They may be placed in a vertical, or in vertical and horizontal directions.

3°. The curve of the arch may be divided into a number of arcs, and the beams placed in the direction of the chords of these arcs.

4°. To these three we may add a fourth, which embraces by far the largest number of centre frames, and is based on two or all of the preceding methods. In this class the beams are not arranged in accordance with any one system, but several; as, for instance, the second and third, in which case, as we shall see hereafter, several straining beams span the arch at different points, and are sustained by inclined struts; or if all three systems are used, we may use the straining beam and inclined struts, and strengthen them by bridle pieces in the direction of the radii.

It would, indeed, be quite a hopeless task to attempt to lay down, in more than a general way, the principles which ought to rule in making a selection of one of these methods to the exclusion of the remaining three. In every case the choice must be determined largely by the circumstances of the case, the points of support, the shape and span of the frame, and the strength required. If the centre is to be "cocket," the arch heavy, the span large, and considerable headway required beneath the frame, the third or fourth arrangement will undoubtedly afford the best results whatever may be the shape of the arch. If the arch is light, the span moderate, and little or no headway is wanted, then the second or first will generally be most convenient.

Theoretically, the first method will in all cases afford the greatest amount of strength and stability with the least amount of material, since the beams are then capable of resisting the most severe strains. Nor can there be any doubt that, within moderate limits, this result actually is attained in practice, and that of two ribs constructed with the same number of beams, of the same quality of wood and similar dimensions, in one of which the pieces are placed

radially, and in the other vertically or inclined, the rib arranged on the former plan will be decidedly the stronger of the two. But, unfortunately, the impossibility of always obtaining firm points of support at the centre of curvature, the difficulty of finding sound, well seasoned timber of such length as would be required in arches of large span, and the relation which exists between the length and strength of beams under longitudinal compression—the strength varying inversely as the square of the length—restricts its application to centre frames of very small span and rise. In semi-circular arches of twelve, fifteen or even twenty feet span, when a horizontal beam can be used at the springing line this arrangement can be used with great success. The frame then consists of the tie beam and two, or if great strength is required, three radial struts which support the backpieces and abut against the horizontal beam at the centre of curvature. These struts, when two are used, should be inclined on the right and left at a little less than 45° to the horizon, so as to meet the backpieces at the point where the voussoirs first begin to press on the rib. A vertical strut is in such an arrangement of little or no use, as no strain of any consequence can possibly reach it; the voussoirs almost ceasing to press on the frame when the keystone is driven down. As these supports are struts and not bridle pieces clamping the backpieces and tie beam between them, the joints, especially in the larger and heavier arches, must be secured by pieces of iron placed across them and bolted to the backpieces and struts, to prevent the joints opening in consequence of the bulging at the crown as course after course of stone is laid on the frame.

In frames for flat segmental arches of a span as great as sixty or seventy feet and rise of about one-fifth the span, as also for ovals of several centres, this radial arrangement may be slightly modified and a frame produced (Figure 2),

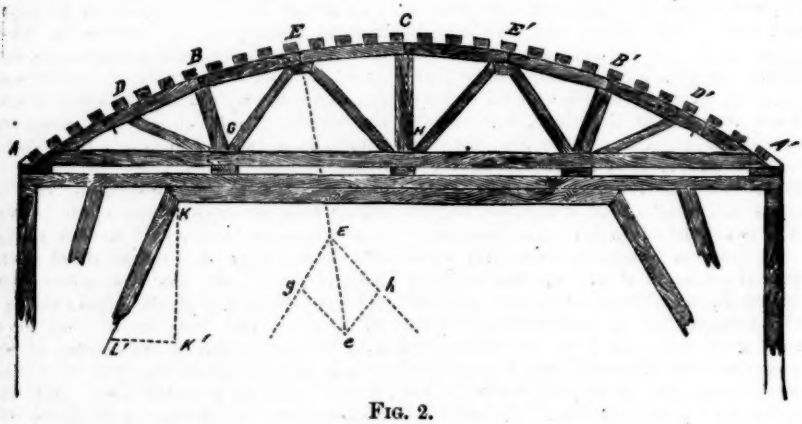

FIG. 2.

which shall meet all the requirements of strength, lightness and economy. The rib in this case again consists of a horizontal tie beam spanning the arch a little above the springing line, generally at the first voussoir that presses on the backpieces, and struts placed in the direction of the radii of curvature and from eight to ten feet apart depending on the weight of the arch. These struts, as it would be impossible to have them actually meet at the centre of curvature, which, for an arch of seventy feet span and fifteen feet rise, would be about forty-five feet from the circumference, go no further than the tie beam and are fastened to it and the backpieces by the iron bands shown in the figure.

When great stiffness is required in the rib, additional braces may be added, as shown in Fig. 2, dividing the rib into a number of triangles. The strains received will then be transmitted through the axes of the beams, and as all unnec-

essary transversal strains will be avoided, the resistance offered by the braces will be the greatest possible. In all centre ribs, the *normal* pressure being in the direction of the radii of curvature, the laggings, backpieces and tie beam, when used, will of necessity be subjected to transversal strain.

Before, however, we proceed to consider the strains to which the beams in centre frames are subjected, and the dimensions we must give them in order that they may withstand the pressure put upon them, we would offer the following practical rule for estimating the pressure of any arch stone in any part of the arch, upon the centre rib, or the pressure upon the rib at any stage of the construction of the arch, as also the pressure when the arch is completed up to the key stone.

It has been well established by the experiments of Rondelet, that a stone placed upon any inclined plane does not begin to slide on that plane until it has reached an angle of inclination to the horizon equal to 30°. It is obvious, therefore, that if the arch stones were placed upon one another they would not begin to press on the centre rib till the plane of the lower joint of one of them reached an angle of 30° with the horizon. It has been found, moreover, that the mortar increases this angle, for hard stone to 34° or 36°, and for soft, porous stone (in semi-circular arches) to 42°. We may, then, consider the pressure to commence in general at the joint which makes an angle of 32° with the horizon. If we suppose the radius to represent the pressure the tangent will then represent the friction, and making the radius unity the friction will be 0.625. The next stone will press a little more, the third still more, and the pressure will thus continue to grow larger and larger with each succeeding course. The relation between the *weight* of an arch stone and its pressure upon the rib in the direction perpendicular to the curve is given by equation :

$$Q = W\ (\cos a - f \sin a) \quad . \quad . \quad (11)$$

in which Q is the pressure, W the weight of the arch stone, f the friction = 0.625, and a the angle the lower joint makes with the vertical. The following table calculated from eq. 11, gives the value of Q for every 2° of curve from the angle of repose = 32° up to 60° :

When the angle which the joint makes with the *horizon* is

	34°	then	Q=.04 W
When	36°	"	Q=.08 W
"	38°	"	Q=.12 W
"	40°	"	Q=.17 W
"	42°	"	Q=.21 W
"	44°	"	Q=.25 W
"	46°	"	Q=.29 W
"	48°	"	Q=.33 W
"	50°	"	Q=.37 W
"	52°	"	Q=.40 W
"	54°	"	Q=.44 W
"	56°	"	Q=.48 W
"	58°	"	Q=.52 W
"	60°	"	Q=.54 W

To take an example : What is the pressure on a backpiece of 20° in length from the angle of repose, the ribs of the frame being placed 5 ft. from centre to centre, and the arch stones 3 ft. in depth and weighing 160 lbs. per cubic foot. We take from the above table the sum of the decimals from 32°—52°=2.26, and multiply this by the weight upon 2° and the product will equal the pressure. The volume of the stones which cover 2°=5×3×2°.

The number of feet contained in 2° is found from the expression 2×.01745329 ×r', in which r' is equal to the radius of the arch *plus one half* the *depth* of the *arch stone.* If we take the radius = 25 ft., then the depth of the stones being 3 ft, r'=26.5 and number of feet in 2° equals .88 ft., whence the volume of the stones which press on the 2° equals 5×3×.88 = 13.4 cubic feet, and the quantity W=2144 lbs. and Q, or the pressure on the backpiece equals 4845 lbs.

If we denote by a the angle included between the upper and lower joints of an arch stone, and suppose every stone in the arch to have the same weight and equal angle a, then the pressure of any number n of such stone upon the rib will be given from the expression

$$Q = \frac{W + \sin \frac{n+1}{2} a}{\sin \frac{1}{2} a} \times (\cos \tfrac{1}{2} na - f \sin \tfrac{1}{2} na) \quad (12)$$

which gives the total pressure on *one half* of the rib.

This equation is found as follows: The pressure perpendicular to the soffit is W (sin $a - f$ cos a), or W (cos $a - f$ sin a), according as the angle a is measured from the *horizon* or from the *vertical* drawn through the crown. If now we denote by a the angle included between the joints of *one* stone, and suppose each stone alike in size and weight, the pressure of any number n of such stones will evidently be found by getting the sum of the *sines* and *cosines* of $n\,a$, or expressed in formula,

$$P = W \text{ (sum of cosines of } n\,a - f \times \text{sum of sines of } n\,a) \quad . \quad . \quad . \quad . \quad \text{Eq. A.}$$

By trigonometry we obtain two expressions for the sum of the sines and cosines of a number of angles in arithmetical progression, viz.:

$$\text{Sin A} + \sin(\text{A}+\text{B}) + \sin(\text{A}+n\,\text{B}) = \frac{\text{Cos}(\text{A}-\frac{1}{2}\text{B}) - \cos(\text{A}+n+\frac{1}{2}\text{B})}{2\sin\frac{1}{2}\text{B}} = \frac{\text{Sin}(\text{A}+\frac{1}{2}n\,\text{B}) \times \sin\frac{1}{2}(n+1)\,\text{B}}{\sin\frac{1}{2}\text{B}}.$$

Also

$$\text{Cos A} + \cos(\text{A}+\text{B}) + \cos(\text{A}+n\,\text{B}) = \frac{-\cos(\text{A}+\frac{1}{2}n\,\text{B}) \times \sin\frac{1}{2}(n+1)\,\text{B}}{\sin\frac{1}{2}\text{B}}.$$

Applying these two equations to the above case, we shall have from eq. A,

$$P = W \qquad \text{Eq. B.}$$

$$\frac{\cos\frac{n}{2}a \times \sin\frac{n+1}{2}a - f(\sin\frac{n}{2}a \times \sin\frac{n+1}{2}a)}{\sin\frac{1}{2}a}.$$

Or taking out the common factors W and $\sin\frac{n+1}{2}a$ we shall have equation B in the form. Eq. (12)

$$P = \frac{W \times \sin\frac{n+1}{2}a}{\sin\frac{1}{2}a} \times \left(\cos\frac{n}{2}a - f\sin\frac{n}{2}a\right)$$

The value of Q may also be obtained from eq. 11 by considering that when the depth of the arch stone is nearly double its thickness; its *weight* rests on the rib at the angle of 60°. Equation 12 is, however, the best, and may be readily solved by logarithms.

For example: let the arch be semicircular and $a = 2°$, then $n\,a = 29°$ and $f = .625$. Put equation 12 in the form

$$P = W\left\{\frac{\cos\frac{1}{2}n\,a \times \sin\frac{n+1}{2}a}{\sin\frac{1}{2}a \times R} - \frac{f\sin\frac{1}{2}n\,a \times \sin\frac{n+1}{2}a}{\sin\frac{1}{2}a \times R}\right\}$$

$\log\cos\ n\,a = \log\cos 29° = 9.941819$

$\log\sin\frac{n+1}{2}a = \log\sin 30° = 9.698970$

19.639789

$\log\sin\frac{1}{2}a = \log\sin 1° = 8.241855$

$R = 10.000000$

18.241855

Difference $= 1.397934 = \log 24.68$

$\log f = \log .625 = -1.795880$

$\log\sin\frac{1}{2}n\,a = \log\sin 29° = 9.685571$

$\log\sin\frac{n+1}{2}a = \log\sin 30° = 9.698970$

19.180421

$\log\sin\frac{1}{2}a = \log\sin 1° = 8.241855$

$R = 10$

18.241855

Difference $= 0.938669 = \log 8.55$

Hence the weight on the half rib is $24.68 - 8.55 = 16.13$ W.

In a frame constructed, as that shown in Fig. 2, the determination of the strains is a matter of great simplicity, and may be had either from arithmetical calculation or by constructing the parallelogram of forces. The strain on any radial strut as B G would be found by calculating from eq. 11 the pressure on D E, taking half of it and supposing it to act at B in the direction B G. The strain on any inclined strut, as E G or E H, may be found by estimating from eq. 11, the strain on B H taking one half of it, and supposing it to act at E in the direction of the radius at that point, and denote by δ and δ' the angles these pieces make with the direction of the force. Then, if these angles are unequal

$$S=\frac{P \sin \delta'}{\sin (\delta+\delta')} \quad \text{and} \quad S'=\frac{P \sin \delta}{\sin (\delta+\delta')} \quad (13)$$

And if the two beams make equal angles with the direction of the force, then the strain in the direction of each is the same and expressed by

$$S=\frac{P}{2 \cos \delta} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Of all methods of calculating the strain on the different beams, by far the simplest, is to actually construct the diagram of forces to a given scale and find the pressure by measurement. In above case, for example, draw E e parallel to the direction of the force to any convenient scale, say $\frac{1}{10}$ inch equal 1,000 lbs., which, supposing the pressure at E=10,000 lbs. will make E e=one inch. From E draw E g parallel to E G; also E h parallel to E H, and eg to E h and eh to E g. Then E g being measured will give the pressure on the beam E G to which it is drawn parallel.

When we have once ascertained the strain which any beam in a frame will have to undergo and resist, the next step is to determine the dimensions, or rather the area of cross section, the beam must have to withstand this pressure without injury. Whatever may be the length of the beam, this section may be obtained from the following formulæ: If the strain is one of compression in the direction of the length, then

$$A=\frac{F}{K}$$

in which A is the section required in square inches, F the crushing force to which the beam is subjected, and K the *resistance* to *crushing*. When the strain is a transverse or breaking strain, then

$$A=\frac{F}{K'}$$

in which K′ is the *modulus* of *rupture* of the beam.

In place of K and K′, however, which are the ultimate resistance to crushing or rupture, we must use $\frac{K}{n}$ and $\frac{K'}{n}$, in which n is the factor of safety, usually taken as 10 for wood. The values of K and K′ are variously stated by different writers on the strength of materials. Those given below for the woods mostly used in centre frames are from Rankine:

Wood.	Value of K in lbs	Value of K′ in lbs.
Ash	9,000	12,000
Pine, yellow.....	5,400	9,900
Pine, red.....	6,200	7,100
Oak, English.....	10,000	10,000—13,000
Oak, American.....	6,000	10,600

If it is not always possible to obtain these values of K and K′, a very safe method, and one easily remembered, is to find from the diagram of forces the strain on a beam in lbs., and divide this by 1,000; the result will be the cross section of the beam in inches. Thus, if a timber is loaded with 36,000 lbs., $\frac{36,000}{1,000}=36$ in., and the beam should be 6 in.×6 in.

Example.

Required the proper dimension of the scantling of a centre rib of a segmental arch of 60 feet span and 9 feet rise; the arch stones to consist of old quarry granite, weighing 165 pounds per cubic foot, and three feet in depth; the rib to be of the pattern shown in Fig. 2. The frames to be placed 5 ft. from centre to centre.

The first step is to find the weight of the arch stone for 1° of the curve. The span is 60 ft., the radius is 50 ft., and the arch stones being 3 ft. thick the radius of the arch passing through their centre is 51.5 ft. The length of 1° is, therefore, .01745329× 51.5 =.89 ft. Then 5×3×.89 = 13.3 cubic ft., the solid contents of 1° of the arch ring, and this multiplied by 165 gives the weight of 1°=13.3×165 = 2195 pounds. Now the arch being a very flat segmental, it is evident that *all* the arch stones will press upon the rib. If then we calculate the weight of the stones between E E′, and suppose them to act with one half their entire weight at C in the direction C H, it is evident that this will be the greatest pressure that C H will be required to support. The arc E E′=20°, and the weight for 1° being 2195 lbs., the pressure at C is 21950 lbs., and the beam C H should be

$\frac{21950}{1000}$=21.9 inches or 4½×5 in. To find the dimensions of E G and E H take eq. 12. Then a=1°, n=20°, f=.625, W =2195.

$$Q=\frac{2195+182236}{.008727}\times(984808-.625\times 173648)=18301 \text{ lbs.}$$

Take this and lay it off to any convenient scale on the line E e, and from E draw E g parallel to E G, and E h to E H and as before $e g$ and $e h$. Then measuring E h by the same scale it will be found to equal 10250 lbs.; the beam E H then must be 3½ in. by 3 in. In the same manner the pressure on B G is found to be 18301 lbs., and the beam must be 4½ in.×4 in. To find the strain on the inclined strut, estimate from eq. 12 the weight of the arch stones between A and C, add to this half the weight of the rib and let the gross weight act vertically at the point K, and lay it off to any scale on the vertical line K K′, and draw K′ L′ parallel to the horizontal tie beam. The line K L′ being measured will give the strain on the beam K L′.

Frames arranged on the second method, with the principal pieces all vertical, afford centres of great simplicity of structure and of almost as much strength as one with radial struts—supposing, of course, that the number and dimensions of the struts are the same in each case—and of much greater strength than one constructed with inclined beams, since the nearer the angle the direction of the strain makes with the fibres of the wood approaches a right angle the less becomes the resistance of the beam. In segmental and oval arches of large span, the difference in the strength of ribs arranged on the vertical and radial plan is comparatively insignificant, as the radius being very large, the vertical beams, especially near the crown where the strain is severe and most strength is required, do not depart much from the direction of the radius.

The objection to this vertical bracing of the frame is that it requires the use of a horizontal tie beam, unless the rib is constructed as a girder resting upon framed abutments of its own. If the former arrangement is used, the struts should be placed from five to eight feet apart, depending on the strength required, and mortised to the tie beam and backpiece. When the beams are of such length that there is danger of their bulging or curving under the load laid on them, they may be strengthened by diagonal braces or horizontal wales. Of the two, the diagonal braces are to be preferred as they not only give stiffness to the posts, but sustain a portion of the load on the backpieces in case any of the piles under the horizontal tie beam should give way. Figure 3 represents the rib of a full centre arch of 75 ft. span ar-

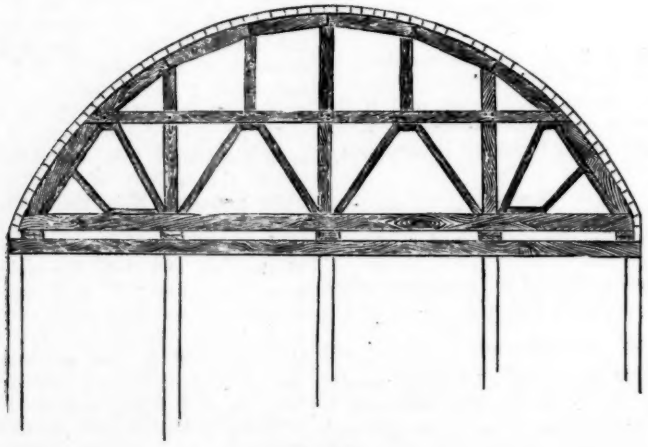

FIG. 3.

ranged with the principal pieces placed vertically and strengthened with a horizontal waling piece made double, and braces abutting under the backpieces. The strains on the different beams composing such a frame, and their necessary dimensions may be computed with ease by the method just explained. It should, however, be remembered that beams which are to be notched must have their dimensions increased beyond those given by calculation, in as much as notching will, even when not very deep, cut down the strength of a beam from one third to one half. In computing the strains on the braces a, a, we may consider the pressure at their abutting point to be the sum of the pressures on the vertical and two inclined braces which meet there, and make no allowance for the resistance of the horizontal beam.

The third and fourth systems of arranging the principal pieces, afford an almost unlimited number of designs for centre ribs, which are especially worthy of notice, in that they are applicable to every possible shape and span that can be given to stone arches, and may be constructed with or without intermediate points of support, according as circumstances will admit. The principles which control such arrangements are few and simple. The beams should as far as possible abut end to end: they should intersect each other as little as may be since every joint causes some degree of settlement, and halving destroys fully half the strength of the beams halved. When the framing is composed of a number of beams crossing each other, pieces tending towards the centre should be notched upon and bolted to the framing in pairs : ties should also be continued across the frame at points where many timbers meet. Particular attention must, furthermore, be given to the manner of connecting the beams so that there shall be no tendency to rise at the crown under the action of the varying load, Figure 4 affords an illustration

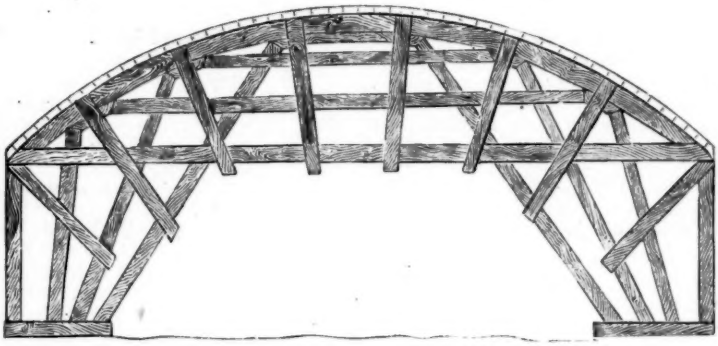

Fig. 4.

of a very simple method of arranging the timbers for arches of small span. The inclined struts abut against horizontal straining beams placed at different points on the soffit, and to add greater strength to the framing, and to prevent the horizontal beam from sagging, bridle pieces are placed in the direction of the radii of curvature. The chief difficulty with such arrangement as this is, that as they require beams of great length they can be used to advantage only in small span arches.

The centre frames for the Waterloo Bridge over the Thames were constructed on this principle, but in this case no horizontal beams were used. Under the backpieces were placed blocks each supported by two inclined struts which made equal angles with the radius drawn through the centre of the block. In a small span arch, these struts would have rested on framed supports placed at the opposite abutments of the arch ; but in the Waterloo Bridge, to avoid the inconveniences resulting from crossing the

struts, and of building beams where struts of sufficient length could not be obtained from single beams, the ends of several struts were received into cast-iron sockets placed at their point of crossing and suspended by bridle pieces.

Figure 5 is a good design for a cocket centre of large span. Here the C F′,

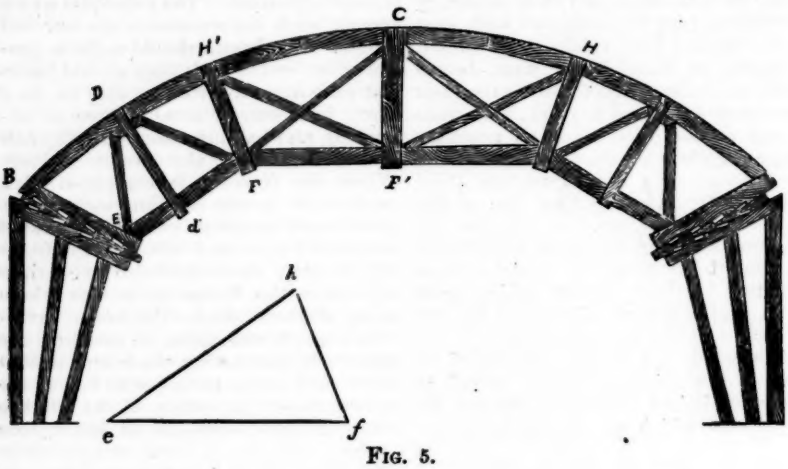

FIG. 5.

H F and D *d*, are placed in the direction of the radii of curvature and made double; the remaining braces are single. In determining the proper dimensions for the scantling of such a frame, we may take $\frac{2}{3}$ of the total pressure on the arc H H′, and suppose it to act at C in the direction C F′, which will evidently be the greatest load this timber will have to sustain. The strain upon the E D F will then be equal to $\frac{1}{2}$ the load on B H, and that on H F as $\frac{1}{2}$ D C. That on the beams E F and F F′ is to be found from the diagram of forces, Fig. 5. Here *h f* which is in the direction of H F produced, represents the pressure on this beam; E *h* is drawn parallel to E F, and *e f* parallel to F F′, which being measured give the strain on E F and F F′ respectively. If it is desirable to obtain the dimensions of the beams with great accuracy we may use the following formulæ: If we assume the relation between the breadth and depth to be .6 to 1 (which is an excellent proportion), then for an inclined beam whose angle of inclination to the horizon is β.

$$d = \sqrt{L\sqrt{\frac{W. \times \cos \beta \times a}{0.6}}} \quad . \quad . \quad (15)$$

And for a horizontal beam

$$d = \sqrt{L\sqrt{\frac{W. a}{0.6}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

In which a is to be found from the expression $\frac{40 \times b \times d^3 \times \delta}{L^3 W} = a$, in which δ is the deflection of a beam whose breadth is b, depth is d, length L, and load W. For pine this quantity a is from .0112 to .0105, and for the best oak .00934. Eq. 15 or 16 will give the depth in inches. If it so happens that the value of a, in the above equation, cannot be obtained either by actual experiment or from tables, we may make the square of one side equal to twice the square of the other, which will give a ratio of 7 to 5 very nearly, and use the equation

$$d = 0.0046108 \times \sqrt[3]{\frac{w. l^2}{\cos b}}$$

Where w is the load, l the length, and b the angle the beam makes with the vertical, and d the dimension of the *smaller* side, equal $\frac{5}{7}$ of the larger. In centre frames, however, such a degree of exactness is rather unnecessary, since, by allowing 1,000 lbs. to the square inch we

can obtain the cross section from the load with all the accuracy desirable in practice.

The transversal strain on any one backpiece or segment of the rib under the laggings may be obtained from the expression

$$S = P \sec \phi \quad . \quad . \quad . \quad (17)$$

ϕ being the angle the backpiece makes with the horizon, and P the vertical component of the pressure on the same piece found by any of the methods already explained, or from

$$P = W\left(L - \frac{x}{r}h\right) \quad . \quad . \quad . \quad (18)$$

W being the pressure on each lineal foot of the segment, L its length; r the radius of curvature at the point in question, x the distance of the lower end of the backpiece from the vertical through the crown of the arch and the centre of curvature, and h the distance between the two ends of the segment measured vertically.

The strain upon any one of the laggings will depend, independent of the weight of the arch stones, on the distance of the ribs from centre to centre, the place the lagging occupies in the arch and the manner in which the laggings are attached to the backpieces of the frame. As regards the latter point, there are two ways of making them fast to the rib. They may be placed directly on the backpiece and nailed to it, or they may be mounted on folding wedges placed between each bolster or lagging and the rib, which latter arrangement will be considered in detail when we come to speak of the striking plate. The bolsters, moreover, may be placed on the rib in such wise that they touch each other, or may be separated by a space equal to their own breadth. The former method is most usually resorted to in the construction of brick arches, and is illustrated in Fig. 4; the latter is used in building stone arches, and is illustrated in Fig. 2. By separating the laggings in this wise a considerable saving of timber is effected, while the air is also given freer access to the joints of the arch and the mortar much sooner dried. When these pieces are separated, it is evident that the cross section of each must be slightly greater than when they are placed touching each other, and that the section of the laggings placed near the crown should be larger than those near the angle of repose. This latter point is not worth considering in practice unless the arch stones are very heavy, for in arches of the ordinary span and weight the saving thus effected in the timber is hardly worth the labor of calculation. In determining the proper dimensions of the laggings, it is sometimes customary to insure against any deflection, by supposing the entire load on each lagging to act at its middle point and calculate for a beam strained in this manner.

TESTING RAILWAY STEEL AXLES.

From "The Engineer."

A PAMPHLET now before us, written in German, contains matter of much interest to British steel makers executing foreign orders for axles. It is too well known to some of our readers that their work is subjected by the inspectors of their foreign customers to very unusual and severe tests, resulting in so much loss and interruption that first-class makers in Sheffield have often refused such orders. Now the results before us cut at the very root of the whole system, and point to the conclusion that the tests adopted by foreign railways especially defeat their own purpose. The paper, the results of many careful experiments, represents a considerable amount of work and time on the part of a countryman of ours in Vienna, a son of the Mr. John Haswell so well known in the profession. Experiments were made on twenty-nine steel carriage axles, of which two were of crucible steel and the remaining twenty-seven of Bessemer metal. Four new iron axles were also tried, and, in addition, two locomotive iron axles.

As is generally known, the mode of procedure usually adopted by continental railway engineers is to take one out of each hundred axles, and test it to destruction. It is usually stipulated in the *cahir des charges* that the whole lot may be rejected if this one, or at most a second, do not stand the trial, as several

English makers have found to their cost. Some of these tests are very severe: such is that required by the Austrian Northern Railway, according to which all five-inch steel axles, when set on supports nearly five feet apart, must undergo blows from a weight of about 7 cwt., falling from a height of nearly 19 ft., increased by two feet for each successive blow. In this way it must withstand a bend of 9 in., and a further bending back of 9 in.—the operations being continued until the axle has withstood more than six thousand foot-pounds. A lighter test is that of the Southern Railway Company, who require for their 4½ in. steel axles that, with a distance between the supports of nearly 5 ft., they shall withstand a bend of more than 9¾ in., under a 7 cwt. monkey, falling from a height of nearly 15 ft. They must then allow themselves to be bent back straight in the same manner without breaking. In fact, almost every other company's engineer has a different test, differing as to the distance between the supports, the weight of the monkey, the height of its fall. The requirements as to extension, compression, and ultimate resistance vary just as much, so that we cannot wonder if the very axles rejected by one company are bought and set to work by another. In truth, the process is merely that generally adopted for rails, of which a certain percentage is taken at haphazard out of the lot, and bent or fractured. This case, however, is scarcely the same as that of an axle—a much more important and responsible component part of a working line.

The increase of traffic has led the German lines of late years to increase the load on the goods trucks by nearly 25 per cent., and they hoped to find their account in replacing iron axles with others of steel. The results in actual practice scarcely responded to these apparently well-founded expectations. In fact, some of their railway engineers are now strongly recommending a return to wrought iron. The truth seems to be that the steel works, in the face of such a system of testing, found it safest simply to deliver the softest and most ductile steel, able to withstand the maximum number of blows from the monkey. Hence the steel axles used are actually of much softer material than those of iron, too soft for their work, liable to permanent sets, and deficient in elasticity. An axle made of lead would as regards ductility certainly beat iron, and withstand more blows without actual fracture. The results in practice are little less than disastrous. It is stated that one of the greatest lines in Austria, possessing extensive steel works of its own, has had, under this system of testing, so many fractures of steel axles that they are being replaced by axles of wrought iron. The practice is certainly not that recommended or adopted by our best railway engineers. As a rule few, if any, English lines test their axles, and a warranty from the maker is usually deemed sufficient. A chance return to this procedure afforded its own lesson. A year or two ago, one of the largest German lines ordered, somewhat in a hurry, a number of axles from an English firm. These axles did not by any means stand the tests; but, on the inspecting engineer telegraphing home for instructions, he was told to receive them. They are now in use, behaving exceedingly well under heavy traffic.

The conclusions to which Mr. Haswell arrives are that the very severe tests have simply resulted in producing steel axles much softer than those of iron; that the proof of one or two axles out of a hundred is no criterion of the quality of steel axles, as axles from the very same works, forged with the greatest care, gave quite different results.

The examination of the question and the experiments carried out by Mr. R. Haswell were undertaken under the auspices of a committee of members appointed by the Vienna "Institution of Civil Engineers and Architects." The results were also very completely laid before them at a meeting held for the purpose. Any action to be taken on the conclusions of their own committee was, however adjourned *sine die* by these gentlemen. Whether they were afraid to accept the responsibility, or, for any other reason, they declined to express any decisive opinion, we hope that this sufficiently important and interesting question will be takan up again, and be brought sooner or later to a definite settlement. It would be regretable if the expenditure of so much work, time, and money should lead to no result.

WATER SUPPLY AND DRAINAGE.*

By W. A. CORFIELD, Esq., M.A., M.D.

IV.

UTILIZATION OF SEWAGE.

Before describing to you the composition of sewage and the ways in which it has been proposed to treat it, I have a few words to say to you about the construction of the apparatus in houses, especially as to the construction of the apparatus used for the removal of such effete matters from houses. I am going to say a word or two on this subject because of the importance of the points connected with it—points that every one of you ought to know.

In the first place, the simplest form of closet that can be used is one with an earthenware pan and syphon, all in one piece, which of course, so long as it is not broken, always retains a certain quantity of water in it. The advantage of this closet is that it can always be readily cleansed. In towns where a more complicated form of apparatus has been tried for the poorer classes and for persons who are not careful, water closets have always failed. One of the great arguments for the supporters of all the dry systems, and especially of the dry earth system, has been that the water system has failed because persons will not take reasonable care; but that has been where the apparatus has been too complicated, as has often been the case in London. Now in towns supplied with apparatus of that sort there is much less risk of anything getting out of order; anything that finds its way into the syphon can be easily got out again, and in fact nothing short of pushing an iron rod in, and making a hole in it, is likely to do any harm, and when a hole is made in it it is easily detected, because the water will not then remain in the syphon; in fact nothing is easier than to discover such a damage.

In the next place they are cheap. One very important point about this system, especially if these closets have to be inside houses or dwellings, is that there should be a hole in the syphon, at the highest point of the pipe above the water, and leading into the drain, and that at this point there should be attached a ventilating pipe. Any sewer gases arising will then be taken off by that pipe, which should be carried to a sufficient height and turned over at the end.

As to the water supply any simple apparatus will do for that; the usual plan is to have a wire, which, when pulled, lifts a plug in the cistern, and water runs down a pipe which generally ends in the side of the pan, the aperture being so directed that it whirls the water round the pan; and the waste pipe of the cistern supplying these may, if that cistern is outside the house, and is only used to supply the closet, be made to end in the same supply pipe. There is very little harm in that, but it should not be done if the same cistern is used for supplying drinking water, which ought not to be the case, although it so often is. A more complicated form of water closet, which is commonly used, requires a word of notice. In this sort you have what is called a D trap, and above that there is what is known as a container, which is a large iron vessel opening below into the water in the trap. Water always remains in this D trap up to the level of the outlet. It is called a D trap from its shape; it is like a D placed thus The pipe which leads from the container (which is the iron vessel immediately under the pan, and in which the basin moves) dips under the surface of the water in the D trap.

Now a few points of caution about this method are necessary. This is the apparatus which is accused of having brought us a large amount of typhoid fever, diarrhœa, and even cholera in large towns, which we should not have had otherwise, and no doubt to a certain extent the system is to blame for it. And I am going to show you where it is to blame for it, and what precautions we have to take to prevent this.

One way in which it is to blame is

* Abstract of lectures delivered before the School of Military Engineering at Chatham.

that the descent pipe, called the soil pipe, is a very convenient place to make the waste pipe of the drinking water cistern end in, and so, very frequently in houses this waste pipe comes down and ends there. The soil pipe goes out of the D trap, and then joins the main soil pipe of the house, or becomes itself the main or perhaps the only soil pipe. This main soil pipe is very seldom open at the top, unless it has been purposely so constructed, and so any foul air in the drain below, or in the soil pipe itself cannot get away, and so it simply goes up the waste pipe of the drinking water cistern, and in fact the waste pipe of that cistern forms the ventilator of the soil pipe, and any poisonous matters in the air in it are absorbed by the water, and drunk, and this is unquestionably one of the causes of the spread of typhoid fever. The waste pipe, however, should not end there, but should end, as I have before told you, outside in the open air.

Now supposing there is no waste pipe ending there, the foul air which accumulates in the soil pipe will have a good many of its ingredients absorbed by this water in the D trap, and they will be given out at the surface of the water into the "container." As soon as the apparatus is worked, and the pan let down so that the water runs out of it, then the foul gases, which have been collecting under pressure in the container, immediately issue into the house.

Now how can that be prevented? There are two ways of preventing it. In the first place, this soil pipe should be open at the top, and then you will never have sewer air with pressure on the D trap. That is quite clear. Or, if you do not carry the soil pipe itself up to the top, there should be, say, a 1-inch leaden pipe going from it up to the top of the house, and turned over, ending at some convenient place, not near the outlet of the chimney. So thus you prevent any foul air from collecting in the soil pipe and rendering the water in the D trap fouler than it need be; but the D trap is always full of water, the apparatus is seldom worked so long as to replace all that water, and so it remains always more or less foul. The foul matters in the D trap putrefy, and so foul air collects in the container, and as soon as the apparatus is worked, this foul air in the container immediately rushes out, because it has been collecting in considerable quantities, a thing which you must all have observed over and over again. That can be prevented perfectly well, so well indeed, as to render closets manageable even in the most inconvenient situations in which they can be placed, and in such situations they frequently are placed in many of the large houses in London; underneath staircases, and close to drawing rooms, or even opening directly out of bed-rooms, and in such places. Although they should, if possible, be removed from such situations, they can be made perfectly sweet in a very simple way, and that is done by making a hole in the container, attaching a small ventilating pipe to it, which pipe is taken through the wall of the house and made to end in some convenient situation, and then you never get any foul air accumulating under pressure, to rush out when the pan is moved and the water in it let fall into the container.

The valve closet is a great improvement upon this, inasmuch as the container is merely a small box in which the valve works, whereas the volume of water used is much greater.

Those are the chief points about this rather complicated apparatus, which is evidently not fit for the use of careless persons. Now for the kind of apparatus fit to be employed when large numbers of persons use the same place. There has been an apparatus contrived called "The Trough Water Closet." I spoke to you before about "Trough Latrines." They are not water closets; they are constructed in very much the same way, but in the "Trough Latrines," the excreta are collected for the day, and then are emptied into a cart and taken away. That is a modification of the "Pail System."

The "trough water closet" may be briefly described thus. Underneath the row of seats there is a trough made of iron or slate, or any convenient material of the sort. This trough at its lower end has a connection with a sewer, the mouth of which is fitted with a plug; which plug can be moved up and down by a lifting apparatus in a separate compartment, which can only be got at by the person who has charge of the place; because, of course, among large bodies

of men, there must always be a man appointed to have charge of this, just as in the case of the earth closets. This compartment can only be got at by this particular man, and he has access in order that he may lift up or let down the plug.

At the other end you have a water tap supplied from a cistern; the man who has charge of the place comes at night, lifts up the plug, lets the contents all run away into the drain, then washes out the trough, lets down the plug, charges the trough with a little water, and leaves it till the next day. That is the "Trough Water Closet," and that is the most convenient form of closet for use by large bodies of persons, especially of careless persons.

As an instance of the success of these closets, I may mention the town of Liverpool. Dr. Buchanan and Mr. Radcliffe, say—"Nothing could be more admirable than the working of the Liverpool arrangement, and nothing could be more marked than the difference between them and what are called water closets, in the poor neighborhoods of London and other large towns." Dr. Hewlett also gives a favorable opinion with regard to these closets. He says—"The trough water closets in use at Liverpool, and the self-flushing tumbler water closets at Leeds, where they answer remarkably well, appear to me to be the best kind for use in poorer districts, especially for closets which are frequented by more than one family." These opinons are sufficient.

The tumbler water closet is very nearly on the same principle. There is a very nearly level trough with a connection with the drain at the lower end; at the other end there is a sort of swing bucket which is placed below a tap. The water is running from this tap continually, but slowly, and the rate at which it shall run is subject to arrangement. As soon as the bucket contains a certain amount of water, it tips over, empties its contents into the trough, washing away whatever is in the trough down into the drain. This plan is also reported to be an excellent one. Of course the water supply and the buckets are placed in a separate compartment, and can only be got at by one person.

We pass on, now, to consider the composition of sewage. This has been well stated in the first report of the Rivers' Pollution Commissioners, in the following words "Sewage is a very complex liquid; a large proportion of its most offensive matters, is, of course, human excrement, discharged from water closets and privies, and also urine thrown down gulley holes. Mixed with this, there is the water from kitchens, containing vegetable, animal, and other refuse, and that from wash-houses, containing soap, and the animal matters from soiled linen. There is also the drainage from stables and cowhouses, and that from slaughter houses, containing animal and vegetable offal. In cases where privies and cesspools are used instead of water closets, or these are not connected with the sewers, there is still a large proportion of human refuse, in the form of chamber slops and urine. In fact sewage cannot be looked upon as composed solely of human excrement diluted with water, but as water polluted with a vast variety of matters, some held in suspension, some in solution."

Now there are great variations in the composition of sewage at different times of the year, and also at different times of the day and night. But there is not a great amount of difference between the composition of the sewage of towns where there are water-closets, and the composition of the sewage where there are not. In the first report of the Rivers' Pollution Commissioners, it is shown that there is "a remarkable similarity of composition between the sewage of midden towns and that of water closet towns. The proportion of putrescible organic matter in solution in the former, is but slightly less than in the latter, whilst the organic matter in suspension is somewhat greater in midden than in water closet sewage."

I must now give you an account of what the average sewage may be taken to be. You may take it that an average sewage has this composition; in 100,000 parts of it there are about 72 of total solid matters in solution, which total solid matters include between four and five of organic carbon, something over two of organic nitrogen, from six to seven of ammonia, and from ten to eleven of chlorine. Besides these 72 parts of dissolved matters, it contains

44 or 45 parts of suspended matters, of which about 24 are mineral, and 20 or 21 organic. Now that is the average. There are extremes. The variation of the London sewage in total combined nitrogen, is from three parts to eleven in 100,000, so that you see there are very considerable differences. And this is partly due to the fact, which is plain enough, that there is a greater amount of refuse thrown into the sewers at one time than at another, but still more to the great variations in the amount of water. As an instance of variation with the time of the year, I may tell you that during the winter before last, the average amount of ammonia in 100,000 parts of the sewage of Romford, was from five to six parts, whereas in the previous summer, the average was only two and a half to four. So that the value varies considerably at different times of the year. It varies because a considerable amount of r. infall is allowed to get into the sewers. It would vary little in towns where very little rainfall is allowed to get into the sewers, and where the water supply is pretty constant throughout the year. The variation in composition during the day and night is very important, and during the night, in many towns, the sewage is very little more than water.

Now as to the value—you may calculate the value of sewage in two ways. Thus you may calculate it approximately, from the number of persons who contribute to make it, and from the value that we have assigned to the refuse matters coming from each person during the year. We have assigned 8s. 4d. a year for these matters, but we will take the lowest value ever assigned to them, which is, that the annual excreta of a human being, taking an average of all ages, are worth 6s. 8d. a head. That value was assigned by Messrs. Lawes and Gilbert, and they have never been valued at less. So that, taking no other refuse at all, if you can get at the excretal refuse matters of a population of three millions, it ought to be worth £1,000,000 per annum, as far as that calculation goes.

But you may calculate the value, again, from the composition of sewage itself. And if you do that, you will find that the money value of the substances dissolved, say in 100 tons of average sewage, is about 15s., while the money value of the suspended matters is only about 2s. The value, then, of these constituents, is about 15s. for the dissolved matters, and 2s. for the suspended matters; that is to say, that 100 tons of average sewage are worth 17s., or about two pence a ton.

If you consider that you do not always get average sewage, or sewage of an average composition, and that very often the sewage is extremely diluted so that, instead of there being something like the dry weather average of sixty tons per head per annum, you often get 100, or even more, it is plain that we must not take so high a value as that I have just stated for it, and so it is usual to take a value of one penny per ton, instead of two pence. If then you take this sewage at a penny per ton, as containing on an average about four grains of ammonia in a gallon, as it does, or between five and six in 100,000 parts, as I said before, then you may consider that sewage is worth one farthing per ton for every grain of ammonia per gallon it contains.

And again, if you take the total amount of sewage of three millions of persons at an average dilution of about 80 tons per head per annum, and put it at the value of 1d. per ton, you will find it comes to almost exactly the same as the calculation made the other way, viz., something over £1,000,000.

Now what are we to do with this sewage which has the value which I have just assigned to it, that is to say, which has that value if you can get the manurial properties out of it? The general plan at present is to turn it into the rivers. This plan has arisen because the sewers we use were originally built for drains, and meant for drains, and therefore naturally discharged into the rivers, and it is no doubt from this circumstance that we have so many attempts to keep a certain proportion of the manurial refuse out of the sewers by means of midden closets, and pail closets, and earth closets and so on, and also with a view to the prevention of the fouling of the rivers. Well there are two kinds of evils that arise from the fouling of rivers, two especially, but there are plenty of others in addition. The first is that these riv-

ers, even when they are large ones, get to a certain extent blocked up by the sediment that is deposited from the sewers; this is the case even with the Thames. In the year 1867 it was pointed out that there was going on a formation of extensive shoals in the River Thames outside the main drainage outfalls near to Barking Creek and Crossness. These deposits were very extensive.

Near the southern outfalls for instance a depth of fully seven feet of deposit was found, and in fact it was going on to such an extent that it threatened to interfere seriously with the navigation. Plans can be seen which show that a narrowing of the bed of the stream had been going on even since this was pointed out in 1867. Besides that, it was also shown that the tide did not carry away the matters suspended in sewage. Experiments were made by Mr. Frank Foster first, and afterwards repeated by Mr. Bazalgette and Captain Burstal—which show that suspended matters, floating bodies, were carried down by the tide to a certain point, and then carried up again farther than the point at which they were originally thrown into the stream, and it is a fact that a certain amount of sewage deposit takes place above the outfalls into the River Thames. Now in small streams as well as in navigable rivers this is of course a very serious matter. That is the first thing. Then perhaps a less important matter, but still one of some importance, is that fish are killed in rivers into which sewage is turned. They are not killed by fresh sewage, but they are killed by the gases which are given off by the decomposing deposit at the bottom of the river, by sulphuretted hydrogen especially.

Then the next danger is the pollution of the drinking water of towns lower down on the rivers, and this has gone on to a very considerable extent, to such an extent that at last Londoners have found out what they are drinking, and all the towns on the River Thames have got injunctions to prevent them turning their sewage into the river. This comes to a climax when you have a case where a town actually turns its own sewage into a river at a particular place, and a mile further down takes out its water supply. That occurs in a town in England at the present moment.

If the towns are not to turn their sewage into a river, what can they do? You see the sewage contains suspended matters and dissolved matters, and both among the suspended matters and dissolved matters are substances that are injurious to health if drunk with water. You see also that the dissolved matters are considerably more valuable than the suspended matters, in the proportion of 15 to 2. But this was not always known, and so the first attempts at purifying the sewage consisted of simply straining it. The sewage was strained and the suspended matters were thus separated and were then sold as manure, or mixed with town ashes and sold for manure, and the somewhat clarified sewage was then allowed to escape into the stream. That is the practice carried on in a great many towns at the present time. The suspended matters are worth comparatively little, and you lose the best portion of the manurial matters. In the second place the purification of the stream is only partially effected, because the clarified sewage that runs into the stream putrifies after it gets there, and you get the stream fouled to a very considerable extent, so that that plan is evidently not sufficient.

Then come different chemical processes. The purification was attempted by various chemical processes, and it is still attempted to precipitate the valuable ingredients dissolved in the sewage as well as the suspended matters. Now there are plenty of ways in which you can clarify foul water, but you see at once that it is not so easy to precipitate those particular matters that are in solution in sewage, because you see in the first place that the most important constituent, or at any rate one of the most important constituents, the most important from its quantity at any rate, is the ammonia. You know perfectly well that you cannot precipitate salts of ammonia on a large scale at all from a dilute solution, and you will see, therefore, at once, that all attempts to precipitate the valuable matter of sewage are likely to fail, even from that cause alone. Then in the next place you have organic matter in solution. Now we do not know of any substance at present which can be used on

a large scale at any rate, that can be relied upon to precipitate organic matters in solution, especially organic matters in the state in which they are in sewage, viz.: in a state of very rapid decomposition, and these are the substances matter which are most dangerous, and which have to be separated, so that you will be prepared to find that most of the precipitation processes have failed. You will find a long description, and an excellent one, of most of these processes in the Second Report of the Sewage Commissioners, published in 1861, giving the results of many analyses. Several of these processes are capable of precipitating at any rate one important ingredient in sewage, and that is the phosphoric acid, an important ingredient which can be precipitated in several ways, and they also—some of them—precipitate some of the organic matters.

Now these are some of the more important precipitation processes brought before the public. In the first place there is the lime process which was practised at Tottenham and Leicester, and some other places, and which merely consisted in adding a certain proportion of milk of lime to the sewage. The result of this process was that no element of agricultural value that was in solution was precipitated by it except the phosphoric acid. The suspended matters were very fairly well removed from the sewage (that you can do perfectly well by straining), and sometimes the amount of organic matter in solution was increased, because some of the organic matter originally in suspension passed into a state of solution, which it always will do by mere agitation, and also the amount of ammonia contained in the sewage was increased, so that by that process, as well as by some others, the water discharged into the river sometimes contained actually more impure ingredients than the sewage contained in solution, some of the organic matters in suspension having passed into a state of solution. A fault of the lime process is that the precipitated matter remaining is alkaline, so that much of the ammonia it contains is given off, and the next thing is that it is nearly worthless.

The Rivers' Commissioners pronounce it "a conspicuous failure, whether as regards the manufacture of valuable manure or the purification of the offensive liquid." The next that I have to mention is a variety of the lime process, in which lime and per-salts of iron were mixed and used. This is a much better plan, because the per-salts of iron will fix the sulphuretted hydrogen and all the phosphoric acid. The fault of this plan is, that it does not precipitate anything else that the lime process did not, and its virtue is this, that it deodorizes the liquid and the precipitate. Salts of iron have been used alone, and they do without doubt deodorize the water, and precipitate the phosphates and the suspended matters, but they only delay the decomposition of it, and again they are too expensive.

Then several processes in which clay was a precipitating ingredient may be mentioned. In the first place, Holden's, in which sulphate of iron, lime, and coal dust, with some clay are used, and Anderson's, which is very much the same as Bird's, which consists in the addition to the sewage of crude sulphate of alumina. Stothert's consists of the addition of sulphate of alumina with sulphate of zinc and charcoal.

And, lastly, the celebrated A. B. C. process. The A. B. C. process was so called from the chief ingredients that were used, with the object of precipitating the sewage, namely, alum, blood and charcoal. You have all probably heard sufficiently about the A. B. C. process lately. You know the Company has attempted to purify some of the sewage of London, at Crossness, and no doubt you have heard that a combined report has been issued by the Engineer and the Chemist of the Metropolitan Board of Works, which report shows perfectly well that although the sewage was at any rate clarified, and although there was a certain amount of purification effected (we can't say exactly what amount, as in this report we have not the analysis of the original sewage); although that was the case, the manure produced was not worth more than twenty shillings a ton, while the cost of producing it was £6 6s. 4d.! Then there is a process known as Hille's process, which is chiefly a deodorizing process. A mixture of lime and tar, and chloride of magnesium is used; the precipitate is of very little value. Carbolates and sulphites of lime,

and magnesia, have also been proposed as precipitants which would also deodorize the sewage. At Carlisle, carbolic acid is used to deodorize the sewage.

There are two or three processes in which phosphates have been used. The idea of using phosphates to precipitate sewage was this,—that the precipitate produced by other substances, like lime and clay, which are useless as manures, will not sell, because it will not bear the cost of carriage; but if you add a substance which is itself a manure, and precipitate the suspended matters with it, then they would sell, and then you would get a manure that is worth carrying.

Now, the first phosphate process has been proposed over and over again. In England it goes by the name of Blyth's process, and the principle of it was this; —there is a salt of phosphoric acid (to wit, the phosphate of magnesium, ammonium and hydrogen, a triple phosphate), which salt is insoluble in water containing salts of ammonia, and it was thought that by adding a salt of magnesia and super-phosphate of lime, or super-phosphate of magnesia and lime water, to sewage, that a precipitate of this triple phosphate would take place. The result was that it was found to be the most expensive process ever adopted, and that a great proportion of the phosphate added went away in the effluent water. The salt in question is not at all insoluble in pure water. It is only insoluble in water containing an excess of ammonia; so that the condition for the success of this experiment was that the water turned into the river was rich in ammonia — an obvious condition for failure of the experiment—and the result was the loss of a great amount of the substances added. That process has failed over and over again.

Then we have a phosphate process patented by Messrs. Forbes and Price. In this process an insoluble phosphate of alumina in large quantities is used, and it is rendered soluble by being mixed with strong hydro-chloric acid. This is mixed with sewage, lime water then is added, and the result is that the suspended matters are carried down very completely, and the sewage is left very clear. All offensiveness is entirely taken away; the effluent water passes off containing all the ammonia that the sewage contained before, and at any rate the greater portion of the organic matter in solution. This process, therefore, could only be used as a preliminary process to some other treatment. I will not say any more about that.

Then recently another phosphate process has come forward, called Whitthread's. That process has been reported on by the Committee of the British Association appointed for the consideration of the treatment and utilization of sewage, and that process is the only precipitating process with respect to which it has ever been said that it does precipitate most of the organic matter that is in solution. It precipitates all the suspended matters, and so far as the preliminary experiments, which were carried on under the supervision of the Committee of the British Association,—as far as those preliminary experiments go, this process depends upon the use of a substance known as di-calcic phosphate, a particular form of phosphate of lime, which seems to have the property of carrying down organic matters in solution. The deodorization is also complete. It does not in any way remove the ammonia in solution, and it remains to be seen whether that process, or indeed any other process, is capable on the large scale of so removing the organic matters in solution that the liquid may at any rate be harmless after it is thrown away.

Lastly, I have to mention to you General Scott's process. General Scott's process consists in mixing the sewage with a certain amount of lime and of clay. It has been reported on by the Rivers' Pollution Commissioners and by the British Association Sewage Committee. About 10 cwt. of lime and 8 cwt. of clay are added to 400,000 gallons of sewage. This mixture of lime and clay is added in considerably greater proportions than the precipitants are added under the other processes. With the others you add as little as possible. With General Scott's process you add a great deal. Well, this mixture is added to the sewage in the sewers before it gets to the tanks, and the result is that the sewage is entirely deodorized, and as soon as it arrives at the precipitating tanks and is allowed to settle, the whole of the suspended matters, including the

lime and clay which have been added, are deposited at the bottom of the tanks. This deposit is run out in a semi-liquid condition as soon as there is enough of it. It is then dried, or it may be compressed by what is known as Needham and Kite's Press. Needham and Kite's Press is a press which has a number of canvas bags in it, into which bags this mud is run. They are then pressed together by a hydraulic press. A certain portion of water is thus squeezed out of the mud, leaving it in a comparatively dry state. It is then taken up in lumps, dried by heat if necessary, and placed in a kiln. A fire is lighted below it with a small quantity of coal, and it burns.

"The area is laid out in square beds intersected with roads and paths, along which are constructed the main carriers which receive the sewage from the outfall sewer and distribute it over the beds." As soon as it is once set alight there is no necessity to put any more coals in the kiln. The sewage deposit with the clay and lime is supplied from the top of the kiln, and it is gradually taken out as it is burnt, through an opening in the bottom, and no more coal is required. There is sufficient organic matter in the deposit for it to go on burning, when once well lighted, for any length of time. The result is the production of a cement, and an excellent cement. This cement can be made of different qualities, and it certainly answers perfectly well as a cement, and the process causes no offence.

The result on the sewage is that it is clarified, and the phosphoric acid contained in solution is precipitated, so that this cement contains phosphoric acid. The ammoniacal salts are left in solution, and the organic matters in solution are not touched by the process, or rather they may occasionally be increased from some of those matters in suspension passing into a state of solution. The cement prepared can be used as ordinary cement; or it has been suggested by General Scott that in places where lime is already used as a manure, it would be considerably better to use this sewage lime, after it has been calcined, on account of the proportion of phosphoric acid in it. It is a process, then, that does not at all pretend to purify the sewage; it merely pretends to afford a means of dealing with the suspended matters of the sewage, and to leave it in a condition in which it is better fitted for treatment afterwards.

We pass on now to the remaining methods for the treatment of sewage, which depend upon the filtration of it through soil. I have described to you the effects of the filtration of foul water through gravel and sand and charcoal. You may say this can be done for water containing a small amount of impurity, but can it be done for water containing a large amount of organic matters both in suspension and solution, as is the case with sewage? Now, filtration may be of two kinds; at any rate there are two principal kinds, downward and upward. You may either pour the water on to the surface of the filter and allow it to pass through, or you may conduct the water underneath the filter, and let it rise up through the filtering material. By the first process, which is known as downward filtration, sewage can be satisfactorily purified on one condition, namely, that the filtration shall be intermittent. I told you how a filter purifies, and you will see at once that this is a necessary condition for the purification of sewage. If you have sewage falling on a filter bed and passing through it to drains below, the organic matters in that sewage are only oxydized, if there is air in the filter; and there cannot be air in the filter unless your process is intermittent. But if your process is intermittent, when you stop pouring sewage on to the filter bed, the remaining water trickles down into the drain below, and so fills your filter with air. You must have an intermittent process.

That shows you again why upward filtration is not capable of purifying sewage. Supposing you have water admitted underneath the filter, and that it is so constructed that it can rise up to the surface of the bed and flow off it, your filter bed is always charged with water. Upward filtration then does not afford the means of aërating the water. By intermittent downward filtration we have a means—as pointed out by the Rivers' Pollution Commissioners (1868)—a means of satisfactorily purifying sewage.

Experiments conducted by filtering London sewage through 15 feet of sand

showed in the first place that "the process of *upward* filtration through sand is insufficient in the purification of sewage from soluble offensive matters; . . . . . on no occasion was the effluent water in a condition fit to be admitted into running streams," but that the "process of intermittent *downward* filtration through either sand or a mixture of chalk and sand effects a very satisfactory purification of sewage when the sewage treated amounts to 5.6 gallons per cubic yard of filtering material in 24 hours; but that the purification becomes uncertain and unsatisfactory when the rate of filtration is doubled, that is when the sewage treated amounts to 11.2 gallons per cubic yard in 24 hours." And so on. And then the amount of purification is given, and the value of different soils as purifying agents. Now, filtration through charcoal has been used in one process, the process known as Messrs. Weare's process; the process has been used in the filtration of the sewage of the workhouse at Stoke-upon-Trent. One would have expected, if the experiment had been conducted properly, that it would have been a success. However, all the sewage of that particular place was exceedingly strong, and although it was purified to a considerable extent by Weare's process, it is not reported favorably on in the report of the British Association Committee, and it has not been employed on a larger scale. Then intermittent downward filtration through soil has been employed as a means of purifying sewage on a very large scale at Merthyr Tydfil by Mr. Bailey Denton, and this has been reported on by the Rivers' Pollution Commissioners and also by the British Association Committee.

"Merthyr-Tydfil contains a population of 50,000—I am now coating from the proof sheets of last year's report of the British Association Committee—but according to information supplied to the Committee, the excretal refuse of not more than two-fifths of this number is discharged into the sewers, although the slops and other liquid refuse from a further like number (20,000) is stated to be admitted. It is not surprising, therefore, that the sewage is, as afterwards appears, weak." "An area of about 20 acres has, under the supervision of a member of the Committee, been converted into a filter bed for the practice of the system of downward filtration originated by the Rivers' Pollution Commissioners, as above described." "The soil of this area consists of a deep bed of gravel (probably the former bed of the River Taff, which is embanked up on the east side and is raised above the valley) composed of rounded pebbles of the Old Red Sandstone and Coal-measure formations, interspersed with some loam and beds of sand, forming an extremely porous deposit, and having a vegetable mould on the surface."

"The land has been pipe-drained at a depth of less than 7 feet, and the pipes are concentrated at the lowest corner, where the effluent water is discharged into the open drain which leads to the river Taff at some distance down the valley."

"The sewage before entering the farm is screened through a bed of 'slag' which arrests the coarser matters. It is applied to the land intermittently, for the area being divided into 4 plots or beds, it is turned on each one for 6 hours at a time, leaving an interval of 18 hours for rest and aëration of the soil." So that you see the right principal is carried out there. When the Rivers' Pollution Commissioners reported on intermittent downward filtration through soil, they said that it could be used to purify sewage. They also said, and it was so thought, that the sewage would be entirely wasted; that the greater amount of it is wasted, as you will directly see; but that it need not be entirely wasted we can see from these experiments at Merthyr-Tydfil, where large crops are grown upon the limited area.

"The surface of the land was cultivated to a depth from 16 to 18 inches, and laid up in ridges, in order that the sewage might run down the furrows, while the ridges were planted with cabbages and other vegetables."

Well now, this process has been carried out on a large scale, and it has been examined with the following results by the "Rivers' Pollution Commissioners," and also by the "British Association Committee," and both sets of examiners have come to the conclusion that the purification is satisfactory. I am not going to give you the numbers,

but I am just going to give you one or two facts about it. In the first place, when you look at the analysis of the sewage of a filter bed like this, you always have to take into consideration the possibility of dilution of the sewage with subsoil water, and in this place the dilution of the sewage with water from the river Taff is considerable. In the summer it was diluted with certainly more than an equal volume of subsoil water, and the gaugings in the winter showed that each gallon of sewage had become mixed with about 2 gallons of subsoil water. When this is allowed for, if you compare the results of the analysis of the effluent water with that of the analysis of the sewage, you find first that the suspended matters are all removed. Then with regard to the dissolved matters, the nitrogen, instead of appearing as it does in sewage as ammonia and organic nitrogen, appears as nitric acid; it has very nearly all been oxydized,—a result that we get from purification of drinking waters by filtration; but the importance and interest of the matter is, that after making allowances for dilution with subsoil water, the total amount of nitrogen in the effluent water is almost exactly the same as the total amount of nitrogen in the dissolved matters in the sewage, although in a different condition; that is to say, that the nitogen retained by the land is almost exactly equivalent to the amount of nitrogen in the suspended matters. The effluent water, I may tell you, was so pure, both in the winter and in the summer, that in the winter nearly all the nitrogen in it was in the form of nitrates and nitrites, and in the summer ⅞ths of it was in the same oxydized and harmless condition.

We have now to consider the subject of sewage irrigation. I have shown you that by filtration through the soil in a particular manner, sewage could be satisfactorily purified; could be purified, in fact, so that the water which had passed through a filter of sand, gravel, or soil, was, practically speaking, drinking water. It is perfectly plain, therefore, that if you enlarge the area of your filter, and pass the sewage through a certain depth of soil, you can in that way, even without the action of plants, satisfactorily purify sewage. But as irrigation farms existed before intermittent downward filtration was thought of, it is neccessary for us to consider whether it is sufficient merely to turn the sewage on to unprepared land—whether it is sufficient that this should be done without making it a necessity that the sewage should pass through the soil.

There are now, at any rate, two classes of irrigationists. One set tells you that an irrigation farm is nothing in the world but a very large filter; that it is absolutely necessary for the purification of the sewage at all times of the year that the sewage should pass through the land. I mean to say they will tell you that at certain times of the year, at any rate, if the sewage does not pass through the land, it will not be satisfactorily purified, and that there is danger of its not being satisfactorily purified at any time.

Others again say that it is not necessary that the sewage should pass through the soil into drains, and that it is not even necessary that the land should be drained in many cases at any rate. In the first place, there can be no doubt that upon almost all impervious soils, sewage can be purified by surface action to a very large extent indeed. At some of our sewage farms they work upon this principal. The sewage does not pass through the soil at all. On the soil plants are growing, and they take up the organic matters, ammonia, &c., from the sewage; and the water which passes off, the overflow, is remarkably pure. But it will remain for us to consider bye and bye, whether, when plant action is least, this would be the case, whether in such cases the effluent water should not be left in an impure condition. Well, now you have sewage brought on to a farm, if you are able to do it, by gravitation, if not, by pumping. On the farm tanks are constructed; as a rule, two tanks, the one being merely to be used while the other is cleaned out. Tanks are considered by many persons as not specially necessary, but they are so, both for the separation and collection of the grosser suspended matters and also for storing the night sewage. The sewage is run out from one of the tanks neither from the top nor from the bottom. At the bottom the sediment is allowed to deposit. At the top the scum accumulates, covers over the surface of

the liquid, and to a great extent diminishes the offensive ordor. The sewage is allowed to run out between the scum at the top and the sediment at the bottom. One of the simplest ways of effecting this is by means of a kind of flood-gate (such as one you may see at Brenton's farm, near Romford), made of pieces of board slid down one over an other; rings are fixed to the sides of these boards, so that one or more of them may at any time be lifted a little by means of a rod with hooks at the end, and then the sewage will run out through the gap made; the lower part of the flood gate keeping back the sludge, and the upper boards keeping back the scum. The sewage flows either directly into the *carriers*, or when it has to be pumped, into the pumping well.

To take the sewage on to the land from the tanks, you may use concrete carriers, as they are the easiest made, and the cheapest. If you want the work to look particularly well, you can use brick-work, or earthenware, at the Tunbridge Wells.

If the carriers have to be lifted above the ground, as where there is a pumping station on the farm itself, they are best made of sheet iron, supported on wooden tressels. They must have simple taps which can be opened by merely taking out a plug.

These carriers run in directions which depend upon the slope of the land.

In the first place, I may tell you that the best sort of land to irrigate is flat land—quite flat—and then that which gently slopes. The main carriers are to run at right angles to the slopes of the land. They are carried under the roads by means of inverted syphons, and then the land is divided at right angles to these carriers into parallel beds.

I am now describing to you the plan which I believe to be the best.

The land is arranged in ridges and furrows, the crests of the ridges running at right angles of the main carriers and down the middle of each bed, so that each bed slopes slightly from the middle towards each side. At Brenton's Farm, where you can see the plan at work, the beds are 30 feet across. Along the top of the ridge there is run a minor carrier. This is merely a groove made along the crest of the ridge by a plough. The taps on the main carriers are just opposite to the beginning of these minor carriers, and the sewage can be let out of the taps and allowed to run along the minor carriers. When the minor carrier is full the sewage overflows and runs over the bed down each side into the furrows between it and the adjacent bed. It may be allowed to run into the minor carrier as long as no pounding occurs in the furrow. That is the "ridge and furrow plan."

There is another system called the "catch-water system." In that plan the sewage is taken in carriers along contour lines. The carrier along the high contour line is filled, and the sewage stopped at a particular place; it overflows and runs down the slope of the land into the carrier below. You can see that at work at many irrigation farms.

There is a variety of that called the "pane and gutter" system. I do not know that I need explain it in detail. The land is divided into pieces or "panes," running down the slope, and at right angles to the main carriers, and the sewage is run over the surface of these "panes" from the higher carriers into the lower ones.

There has been for a long time at Milan a plan of simply flooding the whole of the land, but in this way marshes are produced. The first obvious disadvantage of the catch-water and pane and gutter plans is that some land gets much more than the rest; because all the sewage that flows over the lowest level of a bed must pass over the whole bed from the top. If the land below gets enough, the land above gets too much, besides the fact that the lower beds get all the water that flows off the upper ones. On the other hand, with the "ridge-and-furrow" system I described before, you can just allow each particular bit exactly the amount it wants.

A boy goes along the carrier, turning on and off the taps as they are wanted, and a man walks up and down the ridges and stops the sewage at intervals, so that it overflows the minor carrier on each side and runs over the bed.

Any channels that convey sewage may be open. There is no reason whatever for covering them over. The loss of

ammonia, &c., from the sewage is perfectly inappreciable even after a passage for a very long time through the open air, as proved by the experiments of the Rivers' Pollution Commissioners. You know already that by passing it through soil sewage can be purified. Now, a few words about passing it over the surface of the soil. The Committee of the British Association have made experiments upon this very point; and I have comparisons of the results of the purification of sewage during very severe winter weather at some different farms. Now the first of these is Beddington Farm, Croydon. Here the analysis showed "that the nitrogen that is lost on this farm is lost for the most part in the form in which it came into the land, and that mere surface action (which is relied on here), is not sufficient to cause the oxydization of the ammonia and organic matters contained in the sewage. At the same time the purification effected was certainly very considerable."

Then again, the effluent water at the Norwood farm during the severe frost, was, practically speaking, sewage containing nearly half the amount of the ammonia that the sewage put on the farm did. It contained very little nitrogen in the form of nitrates. You know I told you that the main action of a filter was the conversion of ammonia and the nitrogen contained in organic matters into nitric acid. So that the amount of nitric acid in effluent water is a test of the oxydizing action of the filter. At the same time the analysis of the effluent water at Brenton's Farm, Romford, showed that the purification was very satisfactory indeed, for the effluent water only contained a very small quantity of actual ammonia, that is to say, about 0.14 parts in 100,000, as against 5.6 contained in the sewage, and of albuminoid ammonia only 0.059 parts remained out of 0.524 in the sewage, while the effluent water contained no less than 1.2 parts of nitrogen in the form of nitrates and nitrites.

In winter, when little action of vegetation is going on, mere passage *over* the soil will not purifiy sewage satisfactorily. The effluent water which goes off the land, is, to all intents and purposes sewage. On the other hand, there is a perfectly clear proof, that during winter if you pass the sewage *through* the soil, as at Brenton's Farm, purification goes on just the same as at any other time of the year when vegetation is growing.

Even during the summer there is a risk that the sewage may not be satisfactorily purified where the catch-water principal is adopted. This happened at Reigate, where the sewage was passed over one field and then over another, and the effluent water that came off the lower part of the second field was actualy more impure in several ways than that which came on to it from the first field; that is to say, that this second field was to a certain depth so absolutely saturated with sewage, that the water, or sewage, or whatever you like to call it that came from the first field actually became more impure the further it went. It was in fact made stronger by the amount of evaporation which went on, and is another conclusive proof that surface action is not sufficient.

These results seem to me decisive in favor of the construction of irrigation farms as large filters. Then we come to the practical point—that it is therefore necessary that they should be drained.

On this head the British Association Committee express the following opinion:—

"It may seem almost superfluous for the Committee after so many years of general experience throughout the country, to argue in favor of the subsoil drainage of naturally heavy or naturally wet land, with impervious subsoil, for the purposes of ordinary agriculture; but some persons have strongly and repeatedly called in question the necessity of draining land when irrigated with sewage; and the two farms at Tunbridge Wells, to a great extent, and more especially the Reigate farm at Earlswood, have been actually laid out for sewage irrigation on what may be called the 'saturation' principal; so that it appears to the Committee desirable to call attention to the fact, that if drainage is necessary where no water is artificially applied to the soil, it cannot be *less* necessary after an addition to the rainfall of 100 or 200 per cent. But a comparison of the analysis of different samples of effluent waters which have been taken by the Committee from open ditches into which effluent water was

overflowing off saturated land, and from subsoil drains into which effluent water was intermittently percolating through several feet of soil, suggests grave doubts whether effluent water ought ever to be permitted to escape before it has percolated through the soil."

There are some other plans that have been suggested for the distribution of sewage,—one is by means of the ordinary agricultural drainage. That is obviously perfectly absurd. It is impossible to imagine that sewage could be purified by turning it into agricultural drains below the roots of the plants. Another plan, very much advocated, is to conduct it in pipes just out of reach of the plow, and then to distribute it over the land and plants by means of hose and jet. The thing that is immensely against this, is the expense from the enormous amount of labor; also, that if sewage farms are not to be (and they certainly need not be) nuisances, it is not by squirting the sewage about that we shall attain that object. As to the flood plan which is pursued at Milan, I do not think I need say more than two words about it. It is perfectly plain that we don't want to make sewage marshes, at any rate here. There, at Milan, the water meadows cause ordinary marsh fevers. They do not cause any of the diseases that it was expected sewage farms would cause; they do not favor in any way such diseases as cholera or typhoid fever, which diseases are spread to a very great extent by means of the intestinal evacuations of those suffering from them. I think perhaps as I have gone into the question of public health, I may just say the word or two that I have to say upon that point. I do not think you would find a single case definitely proved against sewage farms — badly conducted as many of them are—where they have been injurious to health, except in this way. If water that contains poison from sewage that has flown over the land and that has not percolated through it, if that water is drunk, it is very likely poisonous. That has been the case once or twice. The farms have not caused by noxious emanations any injury to the health of neighborhoods where they have been placed. I do not think there is the slightest evidence to show that. Then about the water that passes from them. It is said that in certain cases it has poisoned the wells in the neighborhood. There is no evidence of anything of the sort. Where these cases have been inquired into, it has been found that the wells have not been poisoned from the sewage farms, but by foul matters from perfectly different sources. It is true that in one or two cases in which the water which had passed over the sewage-meadows was drunk, a certain number of people got typhoid fever. In sewage-meadows where surface action is relied upon there is considerable danger that the overflow of the channels should be mistaken for fresh water. You understand that when a sewage farm is a large filter, and the effluent water is collected in subsoil drains, this water is perfectly fit to drink. I can tell you of a sewage farm where it is usually drunk by the workmen. There is a well on that particular farm, the water of which is excellent, and there is no reason why it should not be so. Our own drinking water in London, and in most large towns, has got purified from all kinds of impurities by passage through gravel and sand. Dr. Angus Smith tells us that we could not drink rain-water if collected from the clouds anywhere near to large towns; it would be too foul, and would have to be passed through soil in order to be purified.

Well now, the last point that I have to notice in connexion with the public health is the alleged danger from the spread of entozoic diseases by means of sewage irrigation. Dr. Cobbold, the great authority upon entozoa, thinks that if sewage farms are spread much over the land, we shall have more of entozoic diseases, and that deaths from them will become much more frequent, and he even suggested that an entozon which is very fatal in some parts of Northern Africa (the Bilharzia hæmatobia) might become prevalent in this country. But that entozoon is, in the first place, prevalent in those countries especially during the hot seasons. In the second place, we know next to nothing about the different stages it goes through, during which it no doubt inhabits different animals (snails, &c.); and lastly, Dr. Cobbold himself has shown that the larvæ of this parasite

cannot live in impure water. So we may dismiss that at once. Then with regard to ordinary entozoa. In the first place, there is no sort of evidence whatever to show that they have been spread in cattle at farms where irrigation has been going on for 200 years. Professor Christion has distinctly stated that he has never been able to trace entozoic disease to the Craigentinny meadows near Edinburgh, neither is there evidence that this has been done anywhere else. It is very easy to say that the eggs of the entozoa are in the sewage when it is carried on to the land, and that the larvæ will be developed as soon as the plants are eaten by animals. In the first place, you must know that it is necessary that these eggs should be living and fertilized too, and they have the smallest chance of living that anything can possibly have by the time they get with the sewage to the land, for they have a considerable distance to go before they get to the farm; they are tossed about in an alkaline liquid, their natural habitat being acid excretions; they are turned on to the ground and taken down into the soil with the water. However, to prevent any apprehension on this score the simplest thing is to have the grass cut and carried to the stalls, and not to graze animals upon it. Many of the best irrigationists insist upon this.

Some investigations of this matter were made by the British Association Committee.

"An ox which had been fed for the previous 22 months entirely on sewage grown produce" was slaughtered and carcass examined by Dr. Cobbold, Professor Marshall and myself; no trace of any entozoic disease was found in it, although most carefully looked for. Dr. Cobbold suggests several reasons for this result, and one of these is the freedom of the sewage farm from snails and insects, in the bodies of which many of these entozoa go through different stages of their existence; it seems, therefore, that the sewage kills those creatures which are necessary for the existence of these entozoa in their different stages. Dr. Cobbold also examined under the microscope portions of "flaky vegetable tufts," collected from the sides of the minor sewage carriers, and found that, although they contained animal as well as vegetable life, they contained "no ova of any true entozoon." So that you see that as far as we have got positive evidence it is entirely against the theory that entozoic diseases are spread in cattle, and from them down, by means of sewage irrigation.

Now a few words about the crops. The most suitable crop for sewage is Italian rye grass. This plant will take up a very large amount of sewage. If you read the reports of the sewage of Towns Commissioners you will find the results of experiments upon the amounts of meadow grass grown with different quantities of sewage.

There was an average increase of about 4 tons of grass for each thousand tons of sewage applied per acre: the maximum amount of the latter being about 9,000 tons per acre per annum. The largest amount was about 33 tons of green grass per acre in one year, and 37 tons in another. Some of the land was not supplied with sewage at all; other parts with 3,000, 6,000, and 9,000 tons per acre per annum. The increase of produce was much greater with the first 3,000 tons of sewage than it was when the amount was increased from 3,000 to 6,000 tons, and more from 3,000 to 6,000 than from 6,000 to 9,000. So that the increased amount of sewage did not produce a proportionately increased amount of produce. The increase of produce per 1,000 tons of sewage was when 3,000 tons were applied about 5 tons of green grass, when 6,000 tons were applied 4 tons 2½ cwt., and when 9,000 tons were applied 3 tons 3¼ cwt. And the results given by Italian rye grass showed about the same increase of produce. It was also found that an earlier cut of green grass could be obtained by means of sewage irrigation.

Experiments were made about the quality as well as about the quantity, and it was found that the grass contained a smaller actual amount of dry solid matters when grown with sewage, but was richer in nitrogen, and was, in fact, more readily assimilable — more milk could be got from it.

The main result of irrigation farms must be the feeding of cattle and the production of milk. The sewage is turned into Italian rye grass, and is returned to the town from which the sew-

age has come as milk, butter, cheese and beef.

Then, if Italian rye grass can be grown, every grass and almost anything else can as well. You will see that denied even to this day, in spite of the fact that almost everything else has been grown with it. These different plants can be grown upon land which is absolutely and perfectly valueless in an agricultural point of view without sewage, even upon blowing sea sand, and you can see in many parts of England excellent crops now growing by means of the use of this rich manure. Cereals can be grown perfectly well with considerable returns. In 1868 and 1869 (at Lodge Farm, Barking), wheat, winter oats, rye and cabbages were grown. In 1868 wheat was grown on a slope of shingle. It had two dressings of sewage equal to 450 or 500 tons in all. The results were 5 qr. 3 bush., as against 3 qr. 5 bush. without sewage, with 4½ loads of straw, as against 3 to the acre. The winter oats yielded 8 qr. of corn, with three loads of straw to the acre. Among other vegetables must be especially mentioned beet-root. From experiments which have been made there seems very little doubt that beet-root can be grown for the production of sugar in almost any quantity. Professor Voelcker has analyzed some of the beet-roots grown on sewage, and they gave 13.19 per cent. of sugar, while the beet-roots from Holland, Suffolk and Scotland, only gave from nine to ten per cent. of it at the outside.

Well, now a word or two about the times when you don't want sewage on the land. There may be times when you don't want it at all—times when the sewage is too dilute, and the land is very wet, as during heavy floods; and this is a very strong argument for keeping the drainage water, properly so called, out of the sewage, the utilization of sewage is thereby rendered very much easier. The best dilution for sewage is when it represents 25 to 30 gallons per head of the population. If you keep the drainage water as much as possible separate, you can always turn it into it as a diluent when more water is wanted.

The amount of sewage required per acre varies much with different crops and with different soils, but it is usually considered that the sewage of from 35 to 40 persons is sufficient per acre on the average, although in many instances much more than that is applied.

On every sewage farm there should be a piece of fallow land to be used as a filter, not with the view of any great return, but simply with a view to purifying the sewage whether the crop on that particular land happens to want it or not, when it is not wanted on any other part of the farm.

You see, then, that intermittent downward filtration through soil and irrigation farming, with passage of the liquid through the soil, are the only means at present known for purifying sewage, and these may be well continued, with some deodorizing process, which will prevent the sludge in the tanks from being offensive, except where the tanks are in the open country, when this is hardly necessary; and you see also that these processes in themselves are in no way injurious to the health of the neighborhood where they are carried on; one of them, irrigation farming, with the condition mentioned above, also affords the only method known by which the valuable manurial ingredients dissolved in sewage can be utilized—can be turned into wholesome food for man and beast; and it is therefore for you in those parts of the world in which you may be stationed, and where you will have to advise on such matters, to use your influence in obtaining the adoption of the water-carriage system, as before described, in connection with a properly carried out plan of irrigation farming.

The removal of waste matters is the first thing to consider, their utilization the second; where you have both, there you are best able to compete with disease and death.

Extension of Telegraphy in France.—The engineers of the river service of France have been instructed to draw up for the principal navigable watercourses of France plans for the establishment of a telegraphic service similar to that which has just been inaugurated on the Seine. At all the sluices and flood-gates on the river telegraph poles have been set up, and the service of the river is much facilitated by the quick transmission of the state of level.

TOUGHENED GLASS.

From "The Engineer."

SEVERAL months have elapsed since wonder was first excited by the announcement that something approaching in properties to the mythical malleable glass of antiquity had been discovered. It was no new material that was brought forward, and scarcely even a new process, but something very like the old and well-known process, as applied to steel, of tempering it in oil. It was alleged that common glass, or to endeavor to extract from the accounts something a little more exact, that flint glass containing lead, from which the thin plates on which ice is served are blown, or plate-glass containing no lead, could be made greatly more resistant by heating either of these to some known high temperature and plunging the glass into some mixture of oil with tarry matter, this mixture being also heated to some known temperature; and it was added that the air of the apartment in which the operation was conducted must be at some fixed temperature also. But these temperatures, though alleged to be essential to the success of the process, were most unsatisfactorily kept secret, and we were called upon to admire the result of an imperfectly divulged process as enabling the glass treated by to become far more resistant to impact by the recital of such very crude experiments as those recorded by us in April last, in which a 6in. square plate of glass set loosely in a wooden frame like a schoolboy's slate was broken by the fall on to its face of a 2 oz. brass weight from a height of 2ft., whilst it required an iron weight of 8 oz. falling from a height of 6ft. to break a similar, but rather thinner, piece of the same glass which had been subjected to M. La Bastie's process. The difference between the work done in both cases is about as one to twelve, and this really does not represent fully the difference of resisting power in the two cases, because, as has been demonstrated by Dr. Young and others, the power of impulse to produce fracture in brittle bodies increases with the velocities of impact independently of the work lodged in the impelled body, and also with the rigidity of the striking body, the iron weight being here more rigid than a brass one. For all this the experiment is an extremely unsatisfactory one. Why should the plates of glass be set in a wooden frame at all in place of being simply laid upon a flat rigid surface with a square aperture through it nearly the size of the plate? The slightest inequality of bearing or of greater or less looseness wherewith the glass was held in the wooden frame might so materially affect the result as to deprive the experiment of all scientific value, though we may admit it as demonstrative of a great difference in resistance to impact. We are told also that this process greatly increases the resistance of a strip of glass to a steady tensile force; it is added also that if a piece of glass which has been subjected to La Bastie's process be broken by impulse it is not fractured in certain irregular lines radiating from the point of impact, but that the whole piece breaks up into small fragments like those into which a Rupert's drop breaks explosively when its tail is pinched off. Furthermore, it appears by the account of experiments made officially by agents of M. de La Bastie, before glass manufacturers at Pittsburgh, U. S., which we copied from the *Pittsburgh Herald* in a recent impression, that when once the slightest abrasion is made "upon the surface of this glass the entire piece was reduced to powder." If we are to rely upon the facts as stated, the La Bastie glass is as completely in the condition of a Rupert's drop as it might be, if in place of being tempered in oil and tar, it had been dropped liquid into water. Now, if this be so, if in accordance with the somewhat crude speculations which, without anything of experimental support, have been hazarded to account for the changed condition of the glass, we admit for the moment that its exterior and interior layers are held in a state of mutual constraint by unequal contraction, how is it possible that glass in such a state should offer a greater resistance to a steady tensile strain than the same glass, all of whose particles were in a

state of repose, and free from mutual constraints. Is the fact certain that there is any such increase of ultimate tensile resistance conferred by this process? If it really be so, it would only add to the inexplicable character alleged as to other of the results of this process; but for anything that has as yet come to our knowledge, this alleged increase of ultimate tensile resistance may rest merely upon delusive experiment.

Every physicist is aware of the almost insuperable difficulties which attend all attempts to determine, experimentally, the tensile resistance of very rigid bodies. The discrepancy between recorded experiments made by competent physicists upon bodies far less rigid than glass, such as bell metal, speculum metal, &c., amply prove this; and still more so do the results obtained by Messrs. Fairbairn and Tate, upon several species of glass itself. These last indicated a resistance to compression as compared with that to tension so enormously exceeding those of any other known bodies, as to warrant the conclusion that while the experiments on compression made upon short cylinders or prisms may be nearly correct, those recorded for the resistance to tension are greatly below the truth, arising from the almost certain departure, of the line of pull from the axis of the piece. It seems possible, therefore, that the alleged greater tenacity of the La Bastie glass may be a result of its possessing within certain very narrow limits greater flexibility than ordinary glass, so that when subjected to a tensile strain, it is enabled to slightly alter its form, so as more nearly to admit of the pull passing through the axis of the piece. We would not be understood, however, as offering any opinion on this point, but merely suggesting it as one of those to be borne in view in the further experiments that must be conducted before even the most primary facts of this curious subject can be said to be established. In the account to which we have above referred, we find some further statements which appear to us inexplicable, if not contradictory; it is alleged that La Bastie's process was anticipated as far back as the year 1822, at the works of Bakewell, Pears, and Co., and that for the purpose of rendering ordinary glass—flint glass we must presume—less liable to fracture when undergoing the process of ornamental cutting by the glass grinder's wheel, it was previously boiled in fish oil, which it is alleged prevented further annoyance by fracture during the grinding.

Now, as the process of glass grinding or cutting is, until the stage for polishing be reached, neither more nor less than one of abrasion upon a grit stone or a lead lap coated with emery, and as it is stated that the slightest abrasion of the surface causes the La Bastie glass to fly to pieces by a scratch, so it is extremely difficult to see why an exactly opposite result to that recorded should not have taken place by this boiling in oil. Besides the great need of corroboration thus suggested, this alleged American process is no anticipation at all of La Bastie's; the two processes are entirely distinct, and we certainly should not be prepared by any known analogy to believe that cold glass, we presume already annealed in the ordinary way in the "leer," should have its physicial properties altered as described by being kept immersed for any length of time, however great, in fish oil, which boils at a temperature between the melting point of tin and that of lead.

In a lecture delivered at a meeting of the Society for the Encouragement of Arts and Manufacturers on the 2nd of June last, we find some other statements which seem more or less irreconcileable with each other. It is there admitted that if only a corner be broken off by a blow from a plate of this glass the whole plate flies into fragments. It is also admitted that plates of this glass cannot be cut by the glazier's diamond. Not indeed, we must infer, because the surface of the glass be increased in hardness to such an extent as to equal that of the diamond, but that the stroke made by the diamond does not produce a straight and even fracture as in ordinary glass, but one jagged and irregular, and which may diverge more or less from the path that the diamond has described; yet we are informed that this same glass may be engraved upon by fluoric acid, which we should not be prepared to doubt, and also may be engraved by Tilghman's sand blast process, a fact as to which we must entertain much doubt in view of the difficulty of producing a

straight diamond cut, and of the statement that the breaking off of a corner, or a surface abrasion, breaks up the whole piece. Brewster, indeed, found that a considerable portion of the bulbous end of a Rupert's drop might be slowly and carefully ground off upon the lapidary's wheel without that always producing its explosion, provided the surface being ground off was always normal to the axis of the drop, but this is a very different thing from the rough vibratory grinding produced by the ordinary work of the glass cutter. Amongst the points left in obscurity as to the La Bastie process is one which may be far from immaterial. Is it necessary that the glass taken from the glass-house pot, formed by blowing or otherwise and annealed, must be let to cool and then heated again up to redness, or thereabouts, before being quenched in the hydrocarbon oil bath; or, is the result equally attained by taking the glass directly it has become stiffened from the glass blower's pipe or mould, and while still at the requisite high temperature, and at once quenching it in the bath without any intermediate process of annealing and cooling? No experiment nor sufficient information has been recorded as to this, but from some facts stated in the discussion following the lecture to which we have above alluded, it may be inferred that the same effects would be produced if the temperature at the moment of immersion be the same whether the glass, without being allowed to cool on blowing, were at once dropped into the hydrocarbon bath, or whether, having been let cool, it were again slowly heated up to a sufficient temperature and then passed into the bath. The real point of practical difficulty in either case seems to be that the glass when dropped into the bath must be at a temperature so nearly approaching that of its fusion as to be soft and viscous, and that if it be let to cool but a little below this point the effect of the bath is partial and incomplete. Whatever happens as a result of the La Bastie process is something obviously different from that of annealing as heretofore understood, and when closely examined almost all analogy between this process and the tempering of hardened steel in oil disappears.

The steel has been already heated to a temperature at which, if quenched in water, it would become intensely hard, and in that condition, if fractured, breaks with a fracture approaching the vitreous in its character. The heat of the piece is carried off in the water with immense rapidity by the generation of steam, which is condensed as rapidly as it is formed in the remoter parts of the fluid, aided also by the rapid currents induced in the latter by difference of temperature, and also by rapid influx of cold water. Heated to the same temperature and quenched in oil, however, the steel is cooled by convection and conduction, and in a liquid of probably low conductivity and of so much viscidity as to retard circulatory currents; it is, therefore, cooled rapidly indeed as compared with the time of a like amount of cooling in still air, but by no means suddenly. The result is, that whereas the steel suddenly cooled in water may be broken by a sharp blow, in other words, has its range of resilience greatly diminished, in the latter case the metal has its rigidity greatly reduced, and its elastic resilience exalted, so far that from breaking up by a blow or a scratch, it is at once both toughened and strengthened, both as against steady strains and impacts. Nor are the conditions of the process, as here described, indispensable to the result, except in the case of very large masses, to which the process of tempering, known for ages, cannot be applied. The sword blade heated to a redness and quenched in cold water cannot be bent much more than a piece of glass of like size and form without fracture; but let the hardened steel be heated slowly over a fire until it is hot enough to cause tallow or oil to blaze off from its surface, and the blade be now quenched again in water, the result is the well-known strength and elasticity of the sword blade. The only point of real community between the two processes is that the change in physical constitution of the metal appears to take place at about the temperature at which fixed oils begin to volatilize and ignite. But the steel is a compound, and a most peculiar one. No simple metal, so far as experimental knowledge yet goes, presents the faintest trace of those phenomena which characterize more or less the chemical com-

pounds of iron and carbon wherever the percentage of the latter is so small that it is all in combination with the metal. Copper, for example, when heated to a full red or to any high temperature below that, and suddenly quenched in water, is not hardened nor yet tempered, but has its ductility and softness increased to the utmost and its elasticity reduced to the lowest point, and yet the copper may contain metalloids in some state of combination and in almost as large proportions as in the carbon in the finest steels. There therefore seems to be but a faint analogy, and that probably merely a superficial one, between the tempering of steel and this so-called tempering of glass. As to what takes place which produces the physical changes in either case we are almost in equal ignorance. The facts, however, as regards steel have been observed and recorded with considerable care; not so those which respect this process of La Bastie, which was excited so much wonderment and some expectations as to useful results in the arts, which if the facts so far be correctly observed are likely to prove abortive. We can scarcely conceive any economic use to which glass which goes to pieces upon receiving a rough surface scratch—however otherwise resistant—can be put with any advantage. Glass sheets or plates for skylights, conservatories, lighthouse lanterns, &c., would be of little use against hail and storms if a fragment of grit lodged upon their surfaces would, when struck or rubbed, be liable to cause them to fall to powder. The burglar would find this toughened glass in the plate of a jeweler's window quite a boon; and if, too, it should prove ultimately that this glass cannot be cut evenly and readily by the ordinary plate-glass diamond, that difficulty alone will, we apprehend, prove a bar to its application to glazing purposes upon any large scale. Nor would there even seem to be much advantage in the application that has been suggested to watch-glasses, which are always liable to be scratched, and in which a pocketful of glass dust would be no improvement upon three or four large fragments. Nor, indeed, whether the fact be that M. de La Bastie has obtained any patents or not, but yet relies on making a secret of the proper temperature of the glass and of the precise composition of his hydrocarbon bath, omitting the apocryphal temperature necessary in the air, does it seem to us that any considerable advantage can accrue to him as a discoverer beyond the fame of his having been the first observer of some facts of great physical interest. Any one financially interested would soon find out within what limits of temperature the process answered best. The range is very narrow, for if the facts be truly recorded, the temperature of the glass cannot be higher than that at which the glass softens so that the object would lose its form, nor lower than that at which glass begins to assume the rigid condition. For the glasses of wholly earthy bases, such as plate and crown, or white Bohemian glass, it will therefore be below a bright red, approaching a yellow heat in daylight, and for flint or other lead glasses below a dull red. The total reduction in temperature of the glass produced by immersion in the bath would appear to be a range of between 600 deg. and 800 deg. Fah. Again, as to the bath, it would be futile to suppose that there can be any chemical action between its material and that of the glass quenched in it. The effect, whatever its nature, must be a purely physical one, dependent mainly upon the boiling point and degree of viscidity of the liquid; and we cannot but suppose also that these would be hit upon by a few trials. We cannot but think, therefore, that M. La Bastie would be likely to obtain a far better harvest in the way of honestly-attained fame were he fully and in the most exact manner to detail for the use of men of science every part of his very singular discovery. It is one which in its scientific aspects is likely to arrange itself as one of the most important guiding lights amidst the darkness of our ignorance as to the physical changes which takes place by change of temperature in matter. The loose speculations which have found their way freely into print, and pretend to offer a theory to account for the results of the process, are but darkening counsel by words without knowledge, while even the facts to be accounted for remain but imperfectly described; let us have these and we can scarcely doubt that some of the

competent scientific men of Europe —such as Fizeau or Jamin, or M. Luynes, who appears to be already engaged in the investigation in France, or Stokes, Miller, and Clarke in our own country —will be induced to institute and carefully conduct such trains of experiment as may throw some additional light, and, so far as it may go, determinate in character, upon these phenomena, connecting them firmly with known physical laws. Such experiments must be conducted by refined methods and apparatus, and with a previous knowledge of physical optics that very few men, indeed, in any country possess. Had Brewster and Faraday been alive we should already, probably, have received from them much light. The former showed how the lines of strain, both of tension, and compression, in prisms of glass, produced by applied mechanical force, might be rendered visible by the aid of polarized light. Analogous methods and others equally refined, which we do not venture to suggest, will no doubt be employed by such physicists as we have named, and who may undertake this promising investigation. But certainly no light will be thrown upon it— theoretic or practical — by the experiments of the character of those said to have been made by Mr. Kircaldy. We have the highest respect for that gentleman as a faithful recorder of well-made and trust-worthy experiments upon the resistance of materials of construction to extraneous forces as ordinarily applied, but it is no disparagement either to him or to the apparatus with which he operates, to say that he is not the man for any such delicate and far-reaching research as is needed to throw any light upon this matter. The experiments stated, in the above lecture, to have been made by him upon the transverse resistance to static strain of this class are far from accordant, arising in part no doubt from the difficulties already referred to as besetting all such experiments upon a body so rigid as glass; but, probably much more from the specimens submitted to him not being all alike in resisting power, a circumstance which suggests that the process itself may be one deficient in uniformity of result. A lecturer who treats of a subject so full of difficulty as that of the La Bastie process might be expected to be equally certain and conversant with the facts he adduces, and it certainly is surprising to find it stated, as the basis for a somewhat obscure theory of the Rupert's drop, that glass, like water, possesses the property of expanding in volume whilst passing from the liquid to the solid condition. Water and bismuth are the only two bodies now known to increase in volume upon consolidation, and glass certainly does not expand when becoming solid from fusion, nor is it necessary to call in any such condition to account for the phenomena of the Rupert's drop, which was ably treated of by Dr. Brewster, although, as it appears to us, much remains before the remarkable phenomena presented by these drops can be said to be completely understood.

The most pertinent and valuable remarks that were made were those of Mr. Hartley, of Sunderland, during the discussion of this lecture. His view that the de La Bastie glass is no more than a Rupert's drop in another form is, probably, in the main true, yet it presents great difficulties, for how the unstable equilibrium of a Rupert's drop which has been shown to depend, as one of its conditions, upon the perfect form of equilibrium given to the drop by the mode of its production, can exist in a flat rectangular plate, still less in other and more irregular forms, it is difficult to understand.

Signaling on the German Railways.—Several railway companies in Germany are experimenting with different systems of signaling, their interest in the matter being quickened, not by complaints from the ladies, who have long enjoyed the privilege of *Damen-coupés*, but by the number of fires which took place last winter in sleeping carriages. Electric communication is found to be not only costly but untrustworthy, and the so-called "English" system of signaling with a line is not considered satisfactory. In short trains experiments are being made with a cord, which is carried by a ball and socket holder up to the steam-whistle.

— *Iron.*

ON MOLECULES.

From "Engineering."

THE interest elicited by our remarks upon some of the phases assumed by water in one of its conditions, induces us to place before our readers some points suggested by the subject, and to state the views held by the most advanced investigators with regard to the ultimate form of water and matter generally, and its relation to the vaporous or gaseous state. The subject is one that demands our closest attention, for, upon a thorough elucidation and application of the beautiful hypothesis as to the structure of matter, which, of late, under the name of the molecular theory, has been so earnestly studied and so thoroughly elaborated, much of empiric practice in the application of motive power would be swept away with a benefit to science and humanity not to be lightly estimated. In the course of this article we shall, in the interest of junior students, carefully avoid all mathematical formula, and present the subject in its barest outlines, that he who runs may read.

It is possible to conceive of two states in which matter might exist, and from the times of the ancient Greek philosopher down to the present day, these two states have formed subjects for discussion—indeed, our most modern theory may be said to be merely a greatly improved form of one propounded ages ago by Democritus, and in its essential conception the very opposite of that set forth by Anaxagoras. The latter taught that all matter was incapable of infinite division, while the former held that, after a certain extent of divisibility had been reached, matter could be no longer subdivided, and the small particles arrived at called atoms—literally that which cannot be cut—would be the minutest possible in the universe. This is now the almost universally received theory, and by its aid certain phenomena can be explained, for which upon no other known hypothesis could any explanation be suggested.

The term atom has been exclusively appropriated by the chemist, while the mathematician and physicist has preferred to adopt, or share with him, the word molecule to signify those ultimate constituents of matter upon whose motions and relations depends the various states of all bodies, solid, liquid and gaseous; their temperature; and other properties.

The word particle is also freely made use of as involving no hypothesis, and meaning simply a small part of any body. Molecule has been defined by Maxwell as "the smallest possible portion of a particular substance;" and, again, as "that small portion of the substance which moves as one lump in the motion of agitation."

Every substance is now supposed to be composed of an immense number of molecules, which, even in the solid state, are never entirely at rest, and, in the gaseous, are in a state of perpetual violent commotion, rushing about in straight lines in all directions with inconceivable rapidity; and it is this perpetual bombardment, as it has been called, by these little particles that explains the known pressure of gas on the walls of any containing vessel, the incessant impact of the molecules producing the effect of one continual pressure just as upon the eye a succession of rapid flashes of light have the effect of one continuous flame. Of course the molecules, although they are supposed to be separated for a very considerable distance from one another, are perpetually meeting and rebounding, and thus their velocity is interfered with, but there is a certain residuum of speed left, resulting in a mean velocity for the whole. This mean velocity indicates also temperature, and, for the same substance at one pressure, the same mean velocity is always accompanied by the same temperature. But every different substance has a mean velocity of its own for a given temperature, and these have all been calculated, such is the extreme nicety with which the hypothesis is being worked out. Taking, for instance, one of the constituents of water—hydrogen—in the form of gas its mean velocity has been calculated by Joule at over a mile in one second—a speed far greater

than anything we have any practical knowledge of—far above that obtained in artillery practice. The exact velocity is 6,097 feet per second, at a temperature of 32 deg. Fah., and at the ordinary pressure of the atmosphere. A daring attack has been made upon the actual size of the molecules with a result that has every element of probability in its favor. Taking the theorem of Classius as a basis, Thompson has calculated that a cubic inch of gas contains 10^{22} molecules, *i. e.*, a hundred thousand million, million, million; and he deduced from certain optical phenomena in connexion with the thickness of soap bubbles, from the electrical conductivity of metals, and from other considerations, that the diameter of a molecule was about the $\frac{1}{500,000,000}$ of an inch.

To convey some idea of the amount of these magnitudes he says: "If we conceive a sphere of water as large as a pea magnified to the size of the earth, each molecule being magnified to the same extent, the magnified structure would be coarser-grained than a heap of small lead shot, but less coarse-grained than a heap of cricket balls."

It will be observed that we do not specify what gas this is, because a still further development of the theory shows every gas at a given temperature and pressure to contain the same number of molecules, having, however, different weights, and different mean velocities. But—and here comes the means of reducing the theory to a practical issue—the weights and the velocities so counterbalance one another that the resulting energy is the same for every perfect gas. For this argument the perfect equality in size of every molecule of one kind of substance is assumed; that they are so equal is, however, readily proved. Graham has shown how gases can be separated by diffusion through a porous septum; but, if the sizes of the molecules of our gas varied, it would be possible by successive filtrations to get different portions of the gas with molecules of different sizes. The density would then become unequal, and their combining powers different; but whether this separation is looked for in nature or by the hand of man, it cannot be found. Let hydrogen be taken from water, from a hydro-carbon, or from a fallen meteor, its properties, energy, and density, are always alike; and so with all gases. A very convincing proof of the molecular state of matter may be found by taking a cubic inch of water, and, by the application of heat, converting it, in a closed vessel of one cubic foot capacity, into steam. It will apparently fill it. Now if this steam were an expanded solid it would fill the space entirely to the exclusion of all other matter. Does it so behave? It does not. In the first place the result is little interfered with, whether the air is first exhausted or not; for the steam can be made to fill it though the air be there; an inch of ether may be added, and its vapor rises and fills the space as though nothing were there; an inch of alchohol could be similarly vaporized as though nothing were present. The same thing could be done with other volatile substances; and we could go on adding liquid after liquid, and evaporating all into the space at one time. This is very striking proof that the liquid in vaporizing, has had its particles widely separated, and so left room for other particles to be disseminated within its interestices. This position is still further strengthened by observation of the pressure; each liquid exerts a pressure in itself, and if a suitable apparatus be provided to receive the vaporized products and connected with a barometer, it will be found that the pressure of the mixed vapor is just the sum of that of the individual vapors.

Having now indicated the state of matter in the form of gas, that of liquids and vapors may occupy our attention. In a liquid the various motions of the molecules, vibratory, rotatory and rectilinear, exist in a modified form; the rectilinear is slight, while the other two are not much interfered with. If heat be applied the motion of translation is increased as in gases, and, at certain temperatures, different for most substances, vapor begins to form. Water gives off vapor at all temperatures; but this is not the case with all bodies, mercury, for instance, requiring a temperature above 10 deg. C. before it vaporizes. The dynamical theory of heat explains how this change of state occurs. The molecules being in rapid motion and

tossed about in all directions are prevented on all points but the surface of the liquid from escaping; but here they meet with no resistance beyond that mutual attraction which exists among the molecules in the liquid state. But at the surface it will happen that some of them, by a combination of vibratory, rotatory and progressive motions, will be ejected with sufficient energy to carry them out of the sphere of the attractive force of the neighboring molecules, and they then assume the characteristics of gas, moving with the velocity described, and, in this form are truly particles of vapor. If the liquid be enclosed in some vessel, these vapor molecules in their motion of translation will at times strike the surface of the liquid and become imprisoned through the attractive force of the molecules, to be, however, replaced by other projected molecules. This process will continue, and the difference between the number of molecules sent out by the liquid and those caught back again becomes less and less till equilibrium is reached. The vapor is then said to be *saturated*, and its elasticity, under the circumstances, at its greatest point; or, in other words, the vapor exerts its maximum tension at the given temperature and pressure. If then we attempt to decrease the volume by pressure, a portion will be liquefied according to the amount of pressure; but the tension will remain the same. If, however, we pursue the opposite course and endeavor to increase the volume, we shall succeed, and the tension will be lessened; and the more we extend the volume the more exactly do we find it proportional to a reduction of pressure till at last it conforms to Boyle's law, which states that in perfect gases the volume is exactly inversely proportional to the pressure.

But this want of accordance of vapors at their highest state of tension with gases under ordinary conditions of pressure, &c., is more apparent than real, for it is found that the liquefiable gases, such as carbonic acid, nitrous oxyde, &c., when very greatly compressed, also fail to agree with Boyle's law, and act almost the same as vapors. It must not be forgotten that these changes of volume produce important calorific effects, as will readily be imagined when the molecular action is mentally followed. The pressure being now seen to be simply the sum of the energies of a multitude of impacts, it follows that if these impacts take place upon some body that gives way to the shock, the moving force of these molecules will be reduced by just so much as the body gives way to their violence; that is to say, heat or molecular motion will be converted into visible motion. And upon experimental inquiry, such is the case, the vapor or gas in expanding loses heat, and if the expansion be great, the cold produced may be most severe. On the other hand, when a gas is compressed, the molecules, instead of losing their velocity, have an additional quantity imparted to them, and the predicted and observed result is a manifestation of heat, *i. e.*, motion is converted into heat. In the production of steam the atmosphere has to be pushed on one side as it were, or the piston has to be forced away from it: here again heat disappears, and is rendered latent. So it is through the whole range of nature. Where heat or energy is lost sight of it is not destroyed; it is simply stored up for future use, or converted into motion. Physical energy of every kind—chemical action, electrical action—is convertible into heat, and, as Thompson has pointed out, their tendency is continuously in that direction. "There is then in the present state of the known world a tendency towards the conversion of all physical energy into the form of heat."

Our brief survey of this subject, which possesses such a close and wonderful interest to every student of natural phenomena, may suitably close with a shadowing forth of the result which modern speculation and experiment inevitable lead to, and this we cannot do more explicitly than in the words of Rankine, which we extract from the *Philosophical Magazine*:

"Heat moreover tends to diffuse itself uniformly by conduction and radiation until all matter shall have acquired the same temperature."

"There is consequently, Professor Thompson concludes, so far as we understand the present condition of the universe, a tendency towards a state in which all physical energy will be in the state of heat, and that heat so diffused,

that all matter will be at the same temperature, so that there will be an end of all physicial phenomena.

"Vast as this speculation may seem it appears to be soundly based on experimental data, and to represent truly the state of the universe so far as we know it."

RIVERS AND MANUFACTORIES.

From "The Engineer."

One of the most difficult legislative problems in existence lies in framing good laws for the purification of a manufacturing country. It is apparently impossible to draw up enactments of this kind which will not bear hardly on large sections of the community. The welfare of the few should, as a matter of course, be abandoned for the good of the many; but the few will fail to accept the necessity with complaisance. For this reason, the utmost care should be taken to dissever the operation of the law from any appearance of harshness—by no means an easy task to perform. But there is a far wider and deeper question lying beneath the surface of the whole matter. It is quite within the range of possibility to legislate apparently for the good of the many, and with the best intentions possible, and yet to fail to attain the object sought. And it is to this phase of the question that we wish to direct particular attention.

Those who have devoted any thought to the progress of sanitary legislation in this country or abroad, can scarcely have failed to see that the movement in favor of the purification of rivers and the disposal of sewage is a comparatively new thing in the world. Twenty-five years ago people said very little about sewage, and the fact that a river was not clean called forth no comments. So long as sewage was got out of a town and into a stream, local authorities were quite contented, and Parliament took no trouble in the matter. As the country grew in wealth and luxury, and the desire for comfort augmented, better systems for cleaning our towns and our houses sprang into existence, and sons regarded with horror that in which their fathers saw nothing objectionable. This was partly due to the growth of refinement in the nation, and the feeling would no doubt have modified the course of legislation in any case. But a more powerful argument operated forcibly to render the interference of Parliament in sanitary matters essential. Great cities started up on the banks of streams, and as the streams received all the refuse of the cities, their pollution was augmented until it became intolerable to those who dwelt on their banks. Then the nation begun to assert that the rivers of the country must be kept pure; and this is really the object had in view when sewage irrigation or precipitation is employed or demanded. The great sanitary struggle of the day is, in fact, to keep our rivers unpolluted. Now, it never was disputed until within a comparatively recent period, that rivers are the great cleansers of a country; and to this moment it is almost impossible to see how any substitute for their operation in this capacity can be found. So long as the people of Great Britain confined their attention to agricultural and pastoral pursuits there was little difficulty in keeping the rivers clean. In the first place, great cities are impossible in a pastoral country, and whatever the population might be as a whole, the impurities to be disposed of proper to that population would be diffused over a large area, and no concentration of filth would exist. But Great Britain is not a pastoral, or agricultural, but a manufacturing country. Great cities have come into existence within her shores, and sewage is poured into her streams, in certain localities, in such volumes that oxydation and precipitation by natural causes are quite incompetent to keep our rivers pure. Then the law steps in, and compels us to refrain from throwing sewage into our rivers; and so, instead of continuing to use the natural cleansers of the country, we are compelled to seek artificial means of disposing of sewage. We shall not enter here into any consid-

eration of the difficulties which attend this operation—they are familiar, no doubt, to the greater number of our readers; nor shall we deal with non-manufacturing towns, the prosperity of which can be little affected in any way by the operation of sanitary enactments. In the case of manufacturing centres, however, matters assume a very different aspect, and in dealing with them the utmost caution is essential to avoid the passing of laws which may either prove a dead letter or cause serious injury to the property of our manufacturers.

If the worst comes to the worst, the inhabitants of a town can always get rid of what may be termed pure sewage. So far as dwelling houses are concerned, all that comes from them may be turned on to the land, and will assist to grow crops, and promote fertility. But not so with manufacturers. It is quite possible to pollute sewage, and, in certain cases, the refuse cast by manufacturers into sewers may be sufficiently great in quantity and deleterious in quality to render large volumes of sewage utterly unfit to put upon land; and even if the evil does not attain quite to this point, it is certain that in many cases the quantity of sewage is impaired by the refuse mixed with it. The spent alkali, for example, from paper works, requires to be enormously diluted before it can be put upon land without destroying grass. It would, perhaps, be possible, under certain conditions, for a Local Board, to prohibit manufacturers from pouring certain products into the sewers of a town. For example, let it be supposed that the sewage of a town is rented from a Local Board, on the understanding that the sewerage is a valuable commodity. If, then, a manufacturer turns in, say, a quantity of sulphuric acid, he may practically render the sewerage poisonous to grass for the time, and so inflict serious injury on the tenant of the sewage farm. There is no reason, so far as justice is concerned, why the Local Board should not, in such a case, insist that the manufacturer must not pour sulphuric acid into the sewers. Up to the present the point has hardly been raised, because the rainfall and sewage have not been separated; but let a comparatively small town, with a few large paper mills or dye works, once have the separate system of drainage, and send only concentrated sewage on to an irrigation farm, and complaints would quickly be heard. In such a case, what is the wretched manufacturer to do? He cannot use the town drains, and he must not use the river. The reply will be that he must either hit on some means of neutralizing the noxious qualities of the effluent from his works, or he must abandon the business altogether. In the last alternative, thus stated, we have the objectionable side of sanitary legislation. In a word, it is possible to make laws which will ruin given branches of trade. Such laws are intended for the good of the many, but although they may promote health they may be inimical to wealth, and in that case, however good the intentions of the law-makers may be, the practical results of the operations of their enactments will be most unsatisfactory.

It is not difficult to cite instances in which it is impossible to keep streams pure and carry on certain branches of trade at the same time. For example, the water discharged from copper mines is usually excessively bad, and no means have yet been discovered of rendering it inoxious, which are at once moderate in cost and universally applicable. Something may be done under certain circumstances, by precipitating the copper on iron plate, as at the Amlwch mines, in North Wales, but even then the water discharged from the settling pits is destructive to fish. We need hardly say that it cannot be put upon land. There is no possible means of disposing of it but by sending it into the nearest river. The result of an enactment that the water from a given copper mine must not go into a river would be that the mine must be closed. Would it be prudent to enforce the law in such cases? Might it not be, altogether better for the nation, as a whole, that all the fish in a given stream should be killed, and that the copper mine should continue in operation? We shall not stop to answer the question. Those who advocate the purification of our streams at any price are very fond of asserting that if only manufacturers will but try they can easily purify their effluent, and pointing triumphantly to the operation of the Alkali Act, they say that what can be done to purify the air can be done to

purify the water. Now, we are not arguing that manufacturers should be left to follow their own sweet will and pollute streams as they please. Our object is not to deprecate sanitary legislation, but to urge caution in making and putting sanitary laws into force. The good sense of the country may be relied on to a great extent to protect trade interests, but it is not all-powerful, and nothing would tend more to retard progress in the right direction than first passing severe sanitary laws and then enforcing them without discrimination. In spite of all that has been said about the purification of the air, even those who are least particular will agree with us that the atmosphere of Widness is *not* delicious. To make the air of this town good and wholesome, it would, as matters stand, be essential to shut up the chemical works for which the place is famous. We need not say that to use the law for such a purpose would be unjustifiable and impolitic to the last degree. Again, what would become of the iron trade of the country if a vigorous law were put in operation to compel furnaces to consume their own smoke? Yet it would not be more difficult to make iron with smokeless furnaces than it is to avoid the pollution of rivers by feltmakers, dye works, chemical works, or paper mills. The fact appears to be that it is utterly impossible in a manufacturing region to enjoy all that purity of air and water which may be found in agricultural districts.

It is proper that Parliament should interpose to keep the pollution of our streams and our atmosphere within reasonable limits, but the existing degree of pollution of either would not justify the making of laws which might cripple the operations of the manufacturers to whom Great Britain is so largely indebted for her prosperity.

LIERNUR'S IMPROVED SYSTEM OF TOWN DRAINAGE.

From "Journal of Society of Arts."

PUBLIC opinion is daily growing stronger and stronger in favor of legislation to prevent or lessen the scourge of disease that arises from defective drainage, and to stop the pollution of our streams. It is particularly fitting, therefore, that through the medium of this Society attention should be drawn to a system of drainage which, it is averred, is the complete solution of the much vexed problem, sanitarily and technically, and it is anticipated financially also.

It is especially fortunate that the only part of the Liernur system, the practicability of which originally admitted of any doubt, has now been extensively in operation upon the Continent for between three and four years. The fact that it is successful in the highest degree will be apparent when I mention that everywhere it has been put into operation it has received the highest approbation, testified in a practical way by its extension, and that amongst the evidence that may be referred to are such reports as those of the Medical Commission appointed by the Kingdom of Saxony, the International Medical Congress of Vienna, and the whole of the twelve Medical Inspectors of Holland. These last, in a report to the Minister of the Interior, declare unanimously that "sanitarily and for the convenience of the inhabitants, the Liernur system is the best of all systems hitherto known." This favorable evidence has now been confirmed by numerous deputations and commissions from England.

My object, however, is not to string together such evidence, but to give to the Society a description of the principles and technical details of the system.

The end and object of sewerage works is, or should be, to remove the liquid refuse of a town in such a way that there cannot possibly be any pollution, by deleterious matters, of soil, air, or stream, and in such a way that no offence is given to sight or smell, and no habits

imposed upon the people which are likely to be neglected by even the lower orders of the population.

It will be readily admitted that the systems in use in this country cannot pass the standard thus laid down. The fault of all of them is that in one great common sewer there is an indescribable and unmanageable mixture of nastiness, which pollutes both soil and atmosphere, and which, with the exception of those few cases where effective irrigation-farming has been introduced, pollutes streams as well. Irrigation has been pointed to as the great panacea of the sewage evil, forgetful of the fact that it leaves untouched the two great evils of polluted air and soil, which, as much as anything, affect the health of the people.

The Liernur system, on the other hand, is founded on the old Napoleonic maxim, "Beat the enemy in detail"—"Divide and conquer." In other words, never allow any nuisance to get such accumulative power that it cannot be kept under perfect control.

Primarily, Captain Liernur lays down the principle that nothing of a seriously polluting character should ever be allowed to enter the common sewers. For this purpose it is evident that not only must night-soil, and the waste refuse of trade be kept out, but also the fatty and sedimentary products which find their way down kitchen sinks, and the *detritus* from our streets. If this be done, it is evident that the sewer water by itself, though not bright and sparkling, will contain in it no materials of disease to contaminate either soil or air, and will scarcely be dirtier than that which flows from every brooklet in the country after a rainfall.

To keep street *detritus* entirely out of sewers it is necessary that the gullies should be provided with apparatus to detain it. Such an apparatus, it will be seen by this drawing, consists simply in an iron bucket, into which the water, coming from the street, can enter only by a funnel, and from which it can only escape into the sewer by filtering upwards through a thick, loosely-woven straw mat, the mud in suspension being simply cast down into the box.

This mud can be easily removed by scavengers, the bucket in which it is contained being lifted and emptied into a cart. According to the pavement employed will be the frequency of this emptying process. In the ideal town of which I am speaking, Captain Liernur would select the improved wood pavement, as being noiseless, affording a good foothold for the horses, offering a free scope for evaporation and percolation, and as being easily scavenged by machinery. On such a pavement the *detritus* would be necessarily small.

To those who would advocate letting the mud into the sewers I would say, remember that it must be dealt with somewhere, either by separating it from the sewage at the outfall, or dredging it out of the river. Is it not better, therefore, to deal with it at the start, and prevent not only its depositing, choking and fouling in the sewers, but its complicating the sewage problem thereafter. At Belfast, for instance, they have periodically to break open the sewers to clean out the mud.

Next, it is requisite to keep out of the sewers all the waste products of industry. For this purpose it is absolutely necessary that legislation should compel all manufacturers to clear their water before passing it into the sewers. The reason for this, on the principle "divide and conquer," is obvious. It is easier to deal with substances of which we know, or can easily ascertain the component parts, and the different variations that may occur, than when mixed with sewage and waste of all other kinds. In the latter case it becomes an indescribable mixture no man can master, and for which if one day a golden receipt were found, the next day's variation would render it useless. The question as to who should bear the cost of separate purification is one between the manufacturer and the authorities, in no way affecting the principle laid down. As a rule, and as has now been found out by practice (see the working of the Alkali Act and the purification of dye and bleach works, as exemplified by Mr. Thom at the Society's Rivers' Pollution Conference), I believe it would pay the manufacturer, and unless legislation compels him to do the work, there is no possible solution of the sewage problem.

The question for the engineer is, how to test the obedience to the law. Captain Liernur's plan is simple. On the drain-

age pipe from the factory a bend is made, in which some of the water flowing off must always be present. From that bend to the surface of the side walk is an upright pipe, covered by a lid. Through this pipe, by means of a small hand-pump six inches long, the inspector of nuisances can at any time take a sample for analysis.

The sewage problem is not always complicated by the question of manufacturing refuse, but all towns have in some way or another to get rid of human excrement, which is the most dangerous, and at the same time the most valuable, part of sewage. That it is absolutely necessary for sanitary perfection that it be kept out of the common sewers I think no one will deny, if its separate collection can sanitarily and conveniently be effected. To be perfect, such collection involves a great many conditions, which have been well expressed by the Senior Medical Inspector of Holland. A review of them is necessary in order to understand what the pneumatic subdivision of the Liernur system really accomplishes:

"In the first place, a form of closet had to be constructed for use in combination with this system, really perfect in a sanitary and æsthetic sense, inoffensive to sight and smell, and simple and cheap enough for all classes of society, including the poorest and most thoughtless, and yet permitting to the rich those luxuries to which they may be accustomed—qualities which the water closet, as is well known, does not possess.

"Secondly, the use of the water closet for those who could afford the expense of it and desired it, had to remain possible. This demand has been, among many others, a stumbling-block to the introduction of every pail-closet or tub-closet system ever known.

"Further, no laborers had to enter the houses, nor wagons and horses to be seen in the street to remind people of the work of removal, and thus be a nuisance. The work had to be accomplished without necessarily coming to the knowledge of any one, or attracting undue attention.

"But there is another point. As hygiene prescribes a daily removal of fæcal matters at the least, the work had to remain possible from a financial point of view; that is, a great many closets had to be emptied by but one single operation. This involved a very difficult problem; one closet of a row of houses containing much, another a little, and many, perhaps, nothing at all; there were resistances to be overcome, having the greatest differences, by the application of but one motive power at one given moment, and this without failure or faltering. And, notwithstanding this difficulty, the work had to be done without requiring a complicated mechanical apparatus. Finally, no gases could be allowed to escape during or after the process. The pollution of the soil had to be absolutely prevented, and all danger whatever from infection avoided, without, however, destroying the agricultural value of the manure."

To the conditions above stated I would add another most important one. It is, that when from accident, neglect, or as in the case of solitary houses from convenience, the emptying process does not take place daily, the material must be so confined that in no way can anything escape to contaminate air or soil. And further, I would add, that the fatty and sedimentary products of kitchen sinks, which are the same in substance as fæcal matter, with this difference that they are not by several days so far on the road to decomposition, should also be removed under similar conditions to fæcal matter. In Holland, where these matters find their way fresh into the canals at once, and form good food for the fish, they will not trouble to adopt the Liernur system of collecting them, but in this country it is desirable to exclude them from the sewers for two reasons. First, that in time they would give off organic matter in solution and be polluting; and secondly, that their valuable manurial qualities would be lost to the town.

Captain Liernur's pneumatic subdivision for the collection of excrement and sink refuse is the most novel part of his plan of town drainage, for although the other subdivisions have many novel features and improvements, it was the only part about which, previous to its being tried, there could be any doubt as to its being technically possible. These doubts have now been removed by four

years of successful operation. As remarked by the Senior Medical Inspector of Holland, "it is due to the inventor to state that the works executed by him in Amsterdam and Leyden show that he has overcome all the difficulties completely;" and the Director of Public Works supports this by stating that "never has there been in the history of applied science an invention which has come to such perfection in so short a time as the Liernur system."

I will now draw your attention for a while to the technical details of the pneumatic system.

Any large town would be divided into districts of from 250 to 1,000 acres according to local circumstances. Each district would be separate and as independent from any other as if it were an isolated town. Each such district is again divided into small drainage complexes or areas varying from 10 to 50 acres, also according to local circumstances. Each of these little drainage areas is provided with one air-tight cast-iron tank, built in sections so as to be easily enlarged, and with spherical ends to resist atmospheric pressure. This tank, which for distinction sake I call a street tank, is placed at a convenient spot, generally where two or more streets meet, and about three feet under the pavement. From the tank along the several streets extend air-tight cast-iron main pipes five inches in diameter, each perfectly separate and independent of each other. These pipes are connected by branches with the closets of the houses, and are preferably placed in the rear, so as to prevent as much as possible the tearing up of pavements, and to get at closets by the shortest route.

It will be understood that if a vacuum is made in the street tank, a motive power is stored up, which can be let loose upon any given street pipe, and will literally suck towards the tank the contents of the closet pipes. A new vacuum can then be created, and the emptying into the tank be completed.

The question then occurs, how is the vacuum made, and how are the contents of the tank removed. To this I must answer that while the system is being put into operation, that is before the central pumping station and its connections are complete, both the vacuum and emptying processes are the operation of a movable air-pump engine and an air-tight tender, which once a day visit the street tank for the purpose. This mode is merely temporary, and enables the system to be begun in any number of places at the same time without inconvenience. It is largely used in Bohemia, where the system is extensively in operation in barracks and large factories, the demand for the manure in its undiluted fluid condition for the cultivation of beet being very great, the price given being equivalent to 8s. per head per annum. Even this temporary method is without any annoyance to sight or smell. Professor Volger says, speaking of the works at Prague:

"I have repeatedly witnessed the operation with real pleasure. Once an elegantly dressed lady with her servant came close to me, and I noticed how she stooped down over the mouths of the reservoir, watching carefully, with warm hearted interest, the various manœuvres, without the slightest idea of the loathsome substance which was being handled."

The traveling air-pump, engine and tender, however good as a temporary measure, are undesirable as a permanence, nor do they form part of the system when complete. A central station is chosen in which are erected two or three air-pump engines, the aggregate horse-power being only what is required for working purposes, and the division into two or three engines being for convenience in case of cleaning, repairs, or accident. Under the building are air-tight cast-iron reservoirs, in which the engines maintain a vacuum of about three - fourths atmospheric pressure. From the reservoirs are laid, by the most direct routes, air-tight pipes, called central pipes, also five inches in diameter, passing by, and by a couple of connections communicating with, each street tank. One connection is with the top of the tank, and by it air only can be sucked out. The other connection goes down into the well of the tank so as to suck up its contents and remove them to the central reservoirs.

The operation, then, is the following: The air-pump in the central building maintains during the day a vacuum in

the reservoirs underneath, and in the whole length of the central pipes connected therewith. Patrols of two men each parade the district like turnkeys. Coming to a street tank they open the lids, by which access it given to the cocks which shut off each pipe from the tank. One man fixes his key upon the cock connecting the central or vacuum pipe with the tank, and the other has his upon the cock belonging to one of the street main pipes leading to the houses. The moment the first man turns his key he opens the connection between the central station and the tank, the air contained in which is at once exhausted, and a vacuum established, the extent of which is indicated by a small vacuum meter. He then shuts the cock, while the other man, by turning his key, lets loose the force upon one of the pipes leading by its branches to the houses. This action repeated once or twice brings the fæcal matter into the tank. In Amsterdam, for instance, there are as many as 138 houses whose closet pipes are thus cleaned out at once. In the same way a second, third and fourth pipe, each leading to different streets, may be dealt with, and the whole fæcal products of the little drainage complex belonging to the tank be thus collected in it. Before leaving the tank the matter must be despatched to the central station, and this is done by simply opening the second connection of the vacuum pipe, which dips into the well of the tank, when all the matter is at once sucked up and dispatched towards the central station.

So the men patrol the district from tank to tank, simply turning a few cocks; and such is the wonderful simplicity and ingenuity displayed by the inventor, that, with the exception of these cocks, which are of the simplest possible construction, and can be taken up and examined at a moment's notice, there is nothing movable, or which could get out of order, in the whole system of pipes, from and including the closet to the reservoirs of the central building.

The theoretical difficulties to be overcome were great—some closets would be much farther off from the tanks than others, and some might have received no material during the day, and other unequal quantities. It might be imagined, therefore, that by reason of these variations the vacuum might be destroyed and the emptying process prevented. To explain why this is not the case, I must first tell you what cannot be done. It is impossible to propel liquid any great distance through a horizontal pipe by air pressure. The piston of air would break through the column of water, cast it down on the lower segment of the pipe, and passing over would destroy the vacuum. It is evident, therefore, that Captain Liernur could not use horizontal pipes. What, however, can easily be done, is to raise fluids vertically, as in a pump, and bring them to the top of an inclined plane, down which they will flow by their own gravity; consequently, all Captain Liernur's pneumatic pipes are a succession of wave lines, being composed of inclines varying from 1 in 5 to 1 in 250 before the street tanks are reached, according as the fluidity of the matter increases. I may here say, that before reaching the street tanks, and even where water closets are not used, the matter is reduced, by the powerful action of the atmospheric shock, to a consistency resembling that of the thinnest of chocolate. Now, Captain Liernur gives to every branch pipe from the houses to any one street main the same aggregate of vertical risers, breaking them up to hop over an intervening gas or water pipe, or according to convenience. Now, a pump can never empty all the water contained in the receptacle pumped from. There is a minimum that it can never remove. In the same way in these risers, which act like pumps, there must always remain a minimum quantity of fluid just sufficient to fill the riser. In a state of rest this minimum is partly in the riser and partly in the lower end of the gradient of the pipe, forming a complete lock-off of one gradient from another, and a perfect resistance to the vacuum being destroyed even though any particular pipe may have received no additions since last the emptying process took place. The best example I could give of this would be to take two branches from one main pipe, and opposite one another as in the rough sketch. Suppose the riser to be in each case one foot and the branch 100 feet long, with a gradient of 1 in 100; the branch on the right leads, we will say,

to the house of a small family, producing one foot of fluid matter, or just enough to fill the riser, and that on the right to a barrack, where more than a hundred times as much may be expected. We have, therefore, in the barrack pipe a mass filling both pipe and riser, and ready, on the the slightest force, to discharge into the main or street pipe. On the other hand, in the branch pipe of the small family, there is the minimum quantity collected at the foot of the riser. The sucking action is now put in operation in the main pipe. What is the result? The pressure of the atmosphere begins to act, and the barrack pipe rapidly discharges into the main pipe, while the smaller quantity is simply climbing up the riser, and before it has got to the top of the riser to be in a position to discharge, all the surplus quantity in the barrack pipe has gone, and that which is left is simply equal to that minimum which, as I said before, cannot be withdrawn. In this way the fullest pipe always begins to discharge first, the next more full waiting for it, and so on, until the minimum is reached, when simply air breaks through. It is thus that Captain Liernur turns natural laws to his own purposes, and contrives that the minimum quantity gives the maximum resistance, and the maximum quantity the minimum resistance.

As I mentioned before, one of the great advantages of the pneumatic system is that it does not forbid the use of the water closet to those unwilling to give up the use of that expensive and oftentimes troublesome luxury. As, however, all the water added has hereafter to be got rid of, Captain Liernur stipulates that, if economy is to be studied, it is absolutely necessary to have a form of closet, of which there are several known, which only allows of a limited quantity of water being used. His own improved water closet, of which a quart of water is and must be used at each sitting, independent of the will of the individual, has been greatly admired, as being simple in construction, and not likely to get out of order, or to allow of freezing in winter. It would take up too much of your time to describe this, especially as I wish to draw your attention to the Liernur closet without water. This is intended for the working classes, who cannot afford the more expensive luxury, and who would abuse it if they had it. These form 75 to 80 per cent. of our population, and the Liernur closet suitable for them has been declared to be as inoffensive as the ordinary English water closet, and, but for the prejudice existing in favor of that convenience, as well fitted for the rich as for the poor.

The pneumatic privy has no movable mechanism at all, and is used without any water for flushing. The excreta falls into the bottom of a deep funnel, but the size and position of the seat opening is so arranged, and the shape of the funnel is so made, that the extreme area in which the excreta can fall is practically as much limited as would be the case in an ordinary chamber-pot. The effect is that the excreta falls and is collected in a pocket below of but small compass, without touching the sides of the funnel, offering to the air a surface of only five inches. The pocket referred to is one arm of a short bent tube or syphon trap, discharging in a soil-pipe. This discharge is effected by the weight of the excreta, fluids and solids, themselves, each new deposit forcing the former out. Thus the older matter is automatically shut off from further communication with the outer air, and it being well known that no fermentation capable of generating elements dangerous to health takes place within the first thirty hours after production, it is evident that the small surface of fresh substances exposed to the air could at the utmost only throw off offensive gases. To carry these off, however, each funnel is in the upper part made double, the space between being provided with a two-inch ventilating pipe placed close under the seat and leading to the outside of the roof of the house, and furnished on top with a so-called Wolpert's air-sucker. This little contrivance, scarcely known in this country, is very simple, having no movable parts whatever, but is singularly effective; the slightest and almost imperceptible motion of air (which in towns is never quite still) causes an upward current in the pipe. The result is that when the lid is removed from the seat opening a current of air strikes at once downwards into the funnel. From this it is evident that under no circum-

stances can an offensive smell escape from the funnel into the apartment. The funnel itself being of a dark color, it throws no reflected light on the excreta below. It is plain, therefore, that there can be nothing to offend either the sense of sight or the sense of smell, and this is all that can be expected from the best water closet.

Attention must be called to the fact that the pocket of the soil pipe into which the overflow of the privy funnel proper takes place is also ventilated. This pocket, being a bent tube discharging into the branch-pipe, is the real receptacle from which the fæcal matter is permanently removed; all the same, whether it belongs to the water-closet or the pneumatic privy of the system. The pipe provided for the ventilation alluded to serves at the same time for admitting the atmospheric air for the pneumatic process. Hence such air does not enter through the seat opening, nor is the matter in the closet itself removed by pneumatic force.

I have now to describe how it is that the sedimentary products of the kitchen sinks are separated from the rest of the house water, and carried off by the pneumatic pipes. That they are thus separated is due to an exceedingly ingenious apparatus Captain Liernur employs for separating them from the household water running off to the common sewer. It is a trap placed at some suitable spot in the open air, into which all the kitchen and household water on its way to the sewer discharges. In order to flow off into the sewer, all this water must pass upward through a close grating, which acts as a strainer. The sediment is thus thrown down into a sort of pocket, which stands in communication with the privy soil-pipe. When now the pneumatic blast takes place, the pocket of the sink is cleaned simultaneously with the closet pipes, the air to do this, which enters through grating, blowing it clean at the same time.

Before coming to the treatment of the matter collected, at the central station, I wish to say a few words as to the remedies for accidents and stoppages. Remember that the motto of the system is "divide and conquer," and see how this is carried out in every detail. To prevent foreign substances being thrown down and stopping up the pipes, the throat of the privy funnel you will see is made narrower than the pipes are, so that theoretically everything passing the throat will go further, and the most extraordinary things do go through in practice. As a further precaution the closet syphon is crossed by an iron bar, dividing it into two equal spaces. Anything that is small enough to go through will never create any stoppage. Larger articles simply stop up the closet itself, and give the person who transgressed the trouble of removing them, a lesson found in Holland amongst the poorest people to be quite effectual. Further each branch pipe from a house is provided with a stop cock accessible to the officials, by which any house can at any time be shut off from the rest of the system. Presuming a stoppage possible, the whole pneumatic power could be concentrated on any particular house pipe. Such things as leakages again do not occur, and if they did they would be closed up by the earth or substances drawn in by the suction power. In fact it would be impossible to keep a leak open even if desired. But what would be done in case of breakage, is an inquiry I have heard, and the answer is that one would do the same as if a water pipe burst—Mend it! There is this difference, however, between the two cases, a water pipe is so much more likely to break as the pressure is outwards. In the pneumatic pipes the pressure is inwards, quite a different thing. Supposing, however, a pipe did unaccountably break, a thing that has not occurred in experience in the shifty and uncertain soil of Holland, how far would it affect the system? If in the house, the repair could be made at once with or without shutting off the house. If in the branches or main pipe, it could at the utmost affect the houses upon that pipe. Now on account of the risers, the pneumatic pipes never need be deeply laid; below frost depth, that is about three feet, is quite sufficient, so there is no difficulty there. A more serious affair would be the breaking of one of the central pipes communicating the vacuum to the street tanks. This could not fail to be discovered, localized and repaired at once. Suppose, however, an extreme case, in which the repair could not be effected

for a whole week. Then there are two ways open. You can go back for the time to the movable air-pump, or you can simply not perform the emptying process for a week instead of daily as required by the system. This delay has often taken place at Amsterdam through the intentional negligence of an opponent of the system who was in authority. Remember it is the pipes only, not the closets which are emptied by pneumatic force, and there is room in the pipes for a week's product. Indeed, in applying the system to isolated houses on the outskirts of a town or in the country, without any tanks or street pipes, the closet pipes are only intended to be emptied once a week.

In case any one should think that fermentation would set in in the closed pipes during that period, I may mention that the Dutch authorities tried the experiment for thirteen months, and found no change.

I have especially dwelt upon the chance of accidents and their effect upon the system, as I have found the subject quite a bugbear in the eyes of many.

I have now to describe what is to be done with the matter collected at the central reservoir, namely, its conversion into *poudrette*. This part of the Liernur system has not yet been tested on a large scale, although the practicability of it has been sufficiently proved both by actual trial and by experience in sugar-refining, in which a similar process is carried on.

It is a well ascertained fact, that of the heat contained in the steam of a high pressure engine, employed in working the air-pump engine for collecting the matter, but 7 to 8 per cent. are converted into power, the remaining 92 per cent. escaping with the exhaust steam. It is this steam, superheated by being passed through a Green's economizer, and made dry again, that Captain Liernur uses for the drying process. It is conducted through pipes in an upright hermetically closed boiler, into which the fluid manure, after being mixed with a little sulphuric acid, is conducted, and in which by the heat thus imparted a rapid boiling takes place. This is assisted by the fact that a partial vacuum exists in the boiler on account of the vapors of the evaporation being condensed in another receptacle. This other receptacle is engaged in the second or drying process, and consists of a hollow drum of thin red copper, fifteen feet long, and two feet in diameter. This drum revolves in a trough of the already thickened matter, and is itself placed in a hermetically closed vessel, in which a vacuum is maintained. What with the heat imparted to the drum from the inside by the vapors from the first boiling which pass through it, and the vacuum outside, the thin layer of fæcal matter it takes up is thoroughly dried in the course of one revolution, and is scraped off by a fixed knife, falling in little shavings into a box below.

Now, whatever manurial ingredients there are in the sewage must be in the *poudrette*, the air, or the vapors. They cannot be in the vapors, for these come out as pure distilled water, nor in the air, for a vacuum is maintained in the vessel; therefore they must all be in the *poudrette*.

As the *poudrette* has not yet taken its place as an article of commerce, I will not enter into any estimates as to the revenue to be derived from its sale. I would merely point out that it is the pure undiluted material, in a strong concentrated state, and capable of being stored for any length of time, and that I firmly believe that in a town moderately densely populated the revenue would be sufficient not only to cover the annual expenses but to pay the interest of, and redemption on, the cost of the works. In other words, that the pneumatic system would practically cost the ratepayers nothing.

For a similar reason I will make no estimates of cost, as this, as in all drainage works, varies immensely, according to local circumstances.

The sanitary view of the pneumatic system is best described in the following sentences from the account by the Senior Medical Inspector of Holland:

"SANITARY.—The excreta are, from the moment the closets are emptied to the moment when the process is finished and they are converted into dry powder, absolutely deprived of all chance of doing harm, being locked up from first to last in air-tight vessels. The powder itself is harmless, because fermentation in

a dry state is impossible. The water of the excreta has also become harmless, because being driven out by evaporation and condensed again (the vapor passes through an ordinary condenser), it returns to the public streams as distilled, and consequently, pure water. And the gaseous products of the evaporation, perhaps still containing germs of disease, are blown by the air-pump engine, with the rest of the air sucked up out of the tubes and pipes, into the fire place of the boiler, and there are completely burned. No matter, therefore, how infectious the excreta may have been, their power to work evil is stopped forever."

In support of this, I may add that official statements at Leyden aver that the district where the system is applied was formerly noted for the prevalence of typhoid and diphtheria, and that these diseases have now disappeared entirely. Similar evidence is given by the Amsterdam authorities.

Having described the pneumatic subdivision of the Liernur system, I must now shortly state how Captain Liernur would provide for the ordinary drainage, as distinct from the sewerage, if the town were perfectly virgin in this respect. This part of the system is of less interest in England, because most of our towns are sewered, or at any rate have the rudiments of sewers, which they would be unlikely to displace for his improved sewers. In their case he would simply apply the pneumatic system, and, if they liked, his mode of removing street *detritus*, thus relieving the sewers of all dangerous matter. But in a town entirely new as to drainage, he would never adopt the present system, by which not only is great cost incurred, but pollution of soil rendered unavoidable. He would construct the ordinary sewers of vitrified earthenware, so as to be practically impervious, and then nothing would get either in or out except through the proper channels. To provide for the drainage of the subsoil, for which at present the common sewer serves by its porosity, he would follow the farmer's plan of laying agricultural drain-pipes, these emptying at intervals into the ordinary sewer below. These subsoil drains would be laid so as to keep the subsoil water permanently at its lowest level, thus preventing the fluctuations, which cause the alternate inhaling and exhaling by the earth of the atmosphere. The sanitary results of such fluctuations are thus described by Dr. Alfred Carpenter:

"In a porous soil, which easily allows of the rise and fall of the water-line, an amount of air finds entrance and exit equal in volume to the quantity of water which occupies the interstices of the earth. If the soil is impure from cesspool soakage and other sewage abominations, the air drawn into those interstices, as the water-line falls, becomes naturally loaded with the results of sewage decomposition. As the water-line rises this air is expelled and adulterates the purer atmosphere above. If the area is an inhabited one, much of this finds its way into the basements of the houses built upon such a foundation (it gets out more easily there), and the inhabitants naturally suffer from the effects of foul air. If the subsoil is drained by sewer pipes, and the latter are not ventilated in the most efficient manner, another evil also arises. The sewers which were pervious, and allowed leakage into the subsoil of both air and water, which passed downwards, are now sealed to some extent, and all sewer gases find their way into the houses direct. But this is not all. The rise of the water-line is attended by certain evils. Typhoid, and its allied diseases, become prevalent, but as the water-line falls again, another set of diseases become prevalent also, the intermittent class—ague, neuralgia, rheumatic disorders, are rife. It is found in ague districts that the drying, which naturally follows upon the fall of the water-line, is accompanied by epidemics of intermittent fever and its allies, with all those acute sufferings which are called tic, brow ague, megrims, *et id genus omne*. So it becomes the interest of the inhabitants of such a district to keep the water line as nearly as possible at the same level, for its rise or fall is always followed by damage to public health."

Besides the sanitary advantages, there are technical advantages which effect such a saving in cost that these subsoil drains, and the sewers, proper, can be

constructed for about as much as the present imperfect system. The sewers are made much smaller without fear of bursting, even when full, because of the permanent pressure outside of the higher subsoil water. The current in them will at all times be more swift, and hence more cleansing in its action, and if the water contained in them, deprived by Captain Liernur's plans of putrescrible matter and manufacturing waste, be allowed, without further treatment, to enter streams, his sewers can take the most direct route to the nearest water course, thus saving the enormous expense of huge main and intercepting sewers now so much used to carry the whole of the sewage out of town.

The above description of the Liernur system is necessarily brief and imperfect. Any one wishing for minuter details, I would refer to a long technical account written by me in the *Sanitary Record* of 21st November, 1874.

In conclusion, let me say that to strangers to the system a number of theoretical objections will be sure to arise, the answer to which is that in practice they do not arise. The subject, however, is of such paramount importance for England, that a Government official inquiry into the system is very desirable. In this I am sure every one will agree with me, if, as I hope, in the preceding remarks a *prima facie* case has been made out.

HEAT ABSORBED BY EXPANSION.

By S. W. ROBINSON, Professor of Mechanical Engineering, and Teacher in Physics in the Illinois Industrial University.

Written for Van Nostrand's Magazine.

An article in the March number of the Magazine, by Professor H. S. Carhart, of the Northwestern University, indicates, as well as intelligence which has come to the ears of the writer regarding the Professor's experiments, that he is doing good work in the line of College Physical Experiments. Those interested in Western institutions of learning are glad to realize the fact that experimentation as a means of demonstration in educational classes is so widespread as to have reached some of our Western universities.

Though Professor Carhart deserves much credit for his fine experiments of a high order, yet we fear that he has allowed himself to get a little off of the right track in his reasoning, as set forth in the article above referred to, reasoning which the writer has waited several months to see set aright, and which, it is thought, ought not to go uncorrected.

I have, however, only one point to call particular attention to, and that is in regard to the performance of external work by the expanding gas while the receiver is being exhausted by the air pump. The Professor supposes, doubtless by oversight, that in such an experiment the operator performs the external work of expansion of the gas in the receiver, by his own effort in lifting the piston from the gas, a position probably more readily taken, on account of another seeming explanation of the disappearance of heat.

When the piston is raised by the operator, what constitutes the effort? The pressure of the air upon the top of the piston must be lifted. What does it? The pressure of the gas beneath the piston, together with the lift exerted by the pumpman. In exhausting a receiver, the first stroke will be accomplished with less effort than a stroke near the completion of the exhaustion, if a plain single acting cylinder is used. Why? Because the gas in the first stroke, having a greater pressure, performs more of the work of raising the piston against the constant pressure of the outside atmosphere. In other words, the gas in the receiver does perform external work, and, so long as any gas remains in the receiver, continues to aid the operator. If the gas in the receiver were prevented, by a stop-cock or other-

wise, from entering the cylinder while the piston is raised, the operator would perform the whole work of lifting the atmosphere, and the effort, it is readily seen, would be greater with the form of pump supposed, than if the gas were allowed to enter the cylinder freely. When the gas is excluded from the cylinder as the piston is raised, and retained in a fixed elevated position, producing a complete vacuum beneath, what occurs by opening the stop-cock? The reply is: "why, the gas, of course, now performs no external work." Still the receiver will be found cooled as before. Examine the cylinder of the pump. It is heated. And this heating will exactly neutralize the cooling. The gas in the receiver performs work, external to that remaining in it, by ejecting a portion into the cylinder, this work being stored in the moving particles of gas. As they collide against the interior of the cylinder, heat is generated, and just enough, when the particles have come to rest, to represent by that heat the work of expansion having taken place in the receiver. This is in fact nothing, but the famous experiment of Gay Lussac, and Dr. Joule. See Tyndall, *Heat as a Mode of Motion*, p. 89. Maxwell's *Text Book on Heat*, &c. In the exhaustion of a receiver by an air pump, if there were no external pressure, as of air, to be overcome, the piston would need to be held back to prevent its rising too rapidly. In other words, the piston would under these circumstances raise some certain weight. This is the very external work which the gas must perform, and which of course must cool it, as indicated by the pile.

Again the refrigeration of the receiver can hardly be due, to any great extent, to the motion produced among the particles of gas, because this motion, in the receiver itself, must be insignificant. If not for the first *quarter stroke*, that of the succeeding quarter strokes must be, because here the cooling after the first could be due only to the *difference of the motion* in succeeding quarter strokes. Also the motion of the gas in the receiver, caused by so slight a disturbance as produced simply by the departure of a portion of the gas, must involve an amount of work extremely insignificant when compared with the raising of the weight as above mentioned. We must therefore conclude that the refrigeration is due for *very nearly* its entire amount, and when the gas in the receiver has come to rest after the pump strokes, to its *entire* amount, to *external* work.

BALANCED VALVES IN LOCOMOTIVES.

From "The Engineer."

MANY and varying estimates have been made concerning the power wasted in overcoming the friction of slide valves, and probably on no subject has there been a greater diversity of opinion. It has been assumed on the one hand that as much as one-fourth of the power of an engine is thus wasted, and those who hold this doctrine point triumphantly to broken and bent valve spindles as so many proofs that they are right, and that their judgment is sound; others maintain that the loss of power is nominal, and they adduce as evidence that they are right, link motions and eccentrics which have run for years almost without wear. The truth is, that neither party accurately expresses the facts. It is not to be disputed that slide valves do work with a good deal of friction, and so waste power when unbalanced; but it is quite certain that they can never waste one-fourth of the whole force of an engine. Scores of balanced valves are in the market now, or have been, and many of the systems of balancing, or taking off the pressure from the backs of the valves, have been adopted with success in marine and stationary engines, but none appear to have given satisfactory results with locomotives.

In this country there is, unfortunately, not so complete and thorough an interchange of ideas among locomotive super-

intendents as is desirable, and matters are not much better in the United States. There, however, exists the Master Mechanics' Association, and that society appears to be doing really good work, by appointing committees to investigate certain questions and obtain answers from various railroads concerning the experience of the locomotive superintendents. One of the most recent subjects discussed has been the efficiency of various systems of balanced slide valves as applied to locomotive engines. The results of the inquiry are instructive. Fourteen locomotive superintendents have replied to the questions of the Valve Gear Committee. These replies go, on the whole, to show that no satisfactory valve has yet been produced, and that nothing is better than the ordinary slide valve. Some of the valves are well known, others but little known in this country. The evidence concerning them is easily summarized; thus Mr. Hayes, of the Flint and Pere Marquette Railway, tried Richardson's valve, which he ran for two months or about 5,000 miles. The valve seats were in good condition, but the valve leaked badly and was removed. The ordinary valves spared the seats just as much in running the same distance. Mr. Taylor, of the Old Colony Railway, tried no fewer than five varieties of balanced valves, and pronounces them all worthless. Mr. Thompson, of the Eastern Railroad, has used Adams' valves—well known in this country—with good results. The ordinary slide valves in his engines required repairing after 45,000 miles; the Adams' valve ran 66,000 miles. On the Terre Haute and Indianapolis line, balanced valves have been tried with a moderate amount of success. In the course of the discussion which followed the presentation of the report, it became apparent that the general current of opinion was against balanced valves, because they gave no advantage with the increased cost and complication.

It is certain that when large valves are used, as in marine engines, some arrangement must of necessity be adopted to take the pressure off the back, and it can hardly be disputed that if a satisfactory device could be employed with locomotives a decided advantage would be gained; but the device has yet to be obtained, and a wide field for invention still remains unexplored. As regards saving of power, the question may resolve itself into a matter of economy of fuel. Now, all the evidence obtained in America goes to show that no saving of fuel whatever is realized by even the best balanced valves tried. But the question may be regarded from a totally different point of view. A balanced valve renders the handling of an engine easy, and saves wear and tear, not only in the valve and cylinder faces, but throughout the entire valve motion. Some of the American locomotive superintendents stated that with balanced valves the reduction of friction was so great that the reversing lever would remain in any position in which it was placed, although the detent was not in a notch in the sector. But there was also testimony to show that the valves which worked thus easily were all liable to blow through, and that some of them blew so badly that their use actually increased the consumption of steam. It does not appear that any of the speakers were acquainted with Beattie's valve, as used on our South Western Railway with great success; but this can hardly be called a balanced valve, closely resembling, as it does in practice, the old "long D" used by Watt. One proposal came out during the discussion which is well worth attention. It is that valves and seats should have chilled faces. It does not appear to us that any difficulty would be met with in carrying out this system of construction. It is eminently simple, and the excessive hardness of a chilled surface is well known. The experience of one of the speakers is worth notice. Mr. Jackman, of the Chicago, Alton, and St. Louis line, tried a device which we shall allow him to describe in his own words:

"We are using now, on three or four engines, another thing, and I want to state what it is so that every one can take advantage of it. We plane out a groove on the bearing surface of the valve of, say, ¾ in. in width, by almost the length of the valve, leaving the ends inside, then drill a little hole ¼in. at each end down into that place and put the valve in. The first time I tried that was four months ago, I think. When the engine went out from the shop the man who took her out says, 'She blows; I think we shall have to take these valves out and replace them.' So I had a new

set of valves, all fitted exactly every way, so as to just lift the cover off and replace those we had grooved out with the others.

After that I let the man run her on passenger trains. I put the air brake on her and put her into the hands of one of our very good runners, and ran a passenger train between Bloomington and Chicago—one of our heavy trains—and after he had run her two or three times he came to me and said, 'What in the world did you do to the valves of that engine? I used to run that engine before you put her in order on a freight, and she is an entirely different engine now; what did you do to the valves?' I said we did not do anything. 'Why certainly you have done something, for the engine don't handle as she used to handle.' Then I told him just what we had done—that we had cut those grooves, and he said the engine handled a great deal better and a great deal easier. He had run the engine previously a great deal, and he discovered it without knowing anything about what had been done, so that I rather came to the conclusion that there was really some merit in those grooves. The only difficulty there can be in it is this. At a certain point you may have what steam will blow through this ¼in. hole down into the steam port. That may be a disadvantage, but there is only a certain time during the stroke of the engine that that can take place. During the other part of the stroke you have what steam goes through, and from this ¾in. by 14in. or 15in. port, to lift up on the valve and take that much weight off the surface. I wanted to state this fact, and state what this engineer said abont it. On the strength of that experience I have put the same thing into three or four engines since with pretty good results. It has not been more than four months since the experiment began, so I cannot tell you what the result will be finally, but I simply suggest it to the Convention. It is a simple, easy thing to try, and any one can try it, for I do not think there is any patent on it."

It is not very easy to see why this groove gave good results, and we must rest content with Mr. Jackman's verdict. In our opinion, balancing valves will scarcely accomplish the required end in the case of locomotives; and inventors would do well to devote their attention to the production of some species of piston valve which will accomplish what is required. To produce such a valve under the conditions is not an easy task, but the success which has attended Mr. Beattie in dealing with outside cylinder engines may serve to stimulate others to grapple with engines with inside cylinders.

THE BEHAVIOR OF FLUID, WITH SPECIAL REFERENCE TO THE RESISTANCE OF SHIPS.*

From "Iron."

By the term "resistance" I mean the opposing force which a ship experiences in its progress through the water. Considering the immense aggregate amount of power expended in the propulsion of ships; or, in other words, in overcoming the resistance of ships, I trust you will look favorably on an attempt to elucidate the causes of this resistance. It is true that improved results in shipbuilding have been obtained through accumulated experience; but it unfortunately happens that many of the theories by which this experience is commonly interpreted, are interwoven with fundamental fallacies, which, passing for principles, lead to mischievous results when again applied beyond the limits of actual experience. The resistance experienced by ships is but a branch of the general question of the forces which act on a body moving through a fluid, and has within a comparatively recent period been placed in an entirely new light by what is commonly called the theory of stream-lines.

It is convenient to consider first the case of a completely submerged body

* A paper read before the Mechanical Section of the British Association by W. Froude, C. E.

moving in a straight line with uniform speed through an unlimited ocean of fluid. A fish in deep water, a submarine motive torpedo, a sounding-lead while descending through the water, if moving at uniform speed, are all examples of the case I am dealing with. It is a common but erroneous belief that a body thus moving experiences resistance to its onward motion by an increase of pressure on its head end, and a diminution of pressure on its tail end. It is thus supposed that the entire head end of the body has to keep on exerting pressure to drive the fluid out of the way, to force a passage for the body, and that the entire tail end has to keep on exerting a kind of suction on the fluid to induce it to close in again—that there is, in fact, what is termed plus pressure throughout the head end of the body and minus pressure or partial vacuum throughout the tail end.

This is not so; the resistance to the progress of the body is not due to these causes. The theory of stream-lines discloses to us the startling, but true proposition, that a submerged body, if moving at a uniform speed, through a perfect fluid, would encounter no resistance whatever. By a perfect fluid, I mean a fluid which is free from viscosity, or quasi-sodidity, and in which no friction is caused by the sliding of the particles of the fluid past one another, or past the surface of the body. The property which I describe as "quasi-solidity" must not be confused with that which persons have in their minds when they use the term "solid water." When the people in this sense speak of water as being "solid," they refer to the *sensation* of solidity experienced on striking the water-surface with the hand, or to the reaction encountered by an oar-blade or propeller. What I mean by "quasi-solidity," is the sort of stiffness which is conspicuous in tar or liquid mud; and this property undoubtedly exists in water, though in a very small degree. But the sensation of solid reaction which is encountered by the hand or the oar-blade, is not in any way due to this property, but to the *inertia* of the water: it is in effect this inertia which is erroneously termed solidity; and this inertia is possessed by the perfect fluid, with which we are going to deal, as fully as by water. Nevertheless, it is true, I am presently going to show you, that the perfect fluid would offer no resistance to a submerged body moving through it at a steady speed. It will be seen that the apparent contradiction in terms which I have just advanced is cleared up by the circumstance, that in the one case we are dealing with steady motion, and in the other case with the initiation of motion.

The proposition that the motion of a body through a perfect fluid is unresisted, or, what is the same thing, that the motion of a perfect fluid past a body has no tendency to push it in the direction in which the fluid is flowing, is a novel one to many persons; and to such it must seem extremely startling. It arises from a general principle of fluid motion, which I shall presently put before you in detail, namely, that to cause a perfect fluid to change its condition of flow in any manner whatever, and ultimately to return to its original condition of flow, does not require, nay, does not admit of, the expenditure of any power, whether the fluid be caused to flow in a curved path, as it must do in order to get round a stationary body which stands in its way, or to flow with altered speed, as it must do in order to get through the local contraction of channel which the presence of the stationary body practically creates. Power, it may indeed be said, is first expended, and force exerted to communicate certain motions to the fluid; but that same power will ultimately be given back, and the force counterbalanced, when the fluid yields up the motion which has been communicated to it, and returns to its original condition.

Assume a pipe bent, and its ends joined so as to form a complete circular ring, and the fluid within it running with velocity round the circle. This fluid, by centrifugal force, exercises a uniform outward pressure on every part of the uniform curve; and this is the only force the fluid can exert. This pressure tends to tear the ring asunder, and causes a uniform longitudinal tension on each part of the ring, in the same manner as the pressure within a cylindrical boiler makes a uniform tension on the shell of the boiler. Now, in the case of fluid running round within rings of various diameter, just as in the case of railway trains

running round curves of various diameter, if the velocity along the curve remain the same, the outward pressure on each part of the circumference is less, in proportion as the diameter becomes greater; but the circumferential tension of the pipe is in direct proportion to the pressure and to the diameter; and since the pressure has been shown to be inversely as the diameter, the tension for a given velocity will be the same, whatever be the diameter. Thus, if we take a ring of double diameter, if the velocity is unchanged, the outward pressure per lineal inch will be halved; but this halved pressure, acting with the double diameter, will give the same circumferential tension. Now this longitudinal tension is the same at every part of the ring; and if we cut out a piece of the ring and supply the longitudinal tension at the ends of the piece, by attaching two straight pipes to it tangentially, and if we maintain the flow of the fluid through it, the curved portion of the pipe will be under just the same strains as when it formed part of the complete ring. It will be subject merely to a longitudinal tension; and if the pipe thus formed be flexible, and fastened at the ends, the flow of fluid through it will not tend to disturb it in any way. Whatever be the diameter of the ring out of which the piece is assumed to be cut, and whatever be the length of the segment cut out of it, we have seen that the longitudinal tension will be the same if the fluid be moving at the same velocity; so that if we piece together any number of such bends of any lengths and any curvatures to form a pipe of any shape, such pipe, if flexible and fastened at the ends will not be disturbed by the flow of fluid through it; and the equilibrium of each portion and of the whole of the combined pipe will be satisfied by a uniform tension along it. Further, if the two ends of the pipe are in the same straight line, pointing away from one another, since the tensions on the ends of the pipes are equal and opposite, the flow of the fluid through it does not tend to push it bodily endways. This is the point which it was my object to prove; but in the course of this proof there has incidentally appeared the further proposition that a flexible, tortuous pipe, if fastened at the ends, will not tend to be disturbed in any way by the flow of fluid through it. This proposition may to some persons seem at first sight to be so paradoxical as to cast some doubt on the validity of the reasoning which has been used; but the proposition is nevertheless true, as can be proved by a closely analogous experiment, as follows:—Imagine the ends of the flexible tortuous pipe to be joined so as to form a closed figure; there will then be no need for the imaginary fastenings at the ends, since each end will supply the fastening to the other. Then substitute for the fluid flowing round the circuit of the pipe a flexible chain, running in the same path. In this case the centrifugal forces of the chain running in its curved path are similar to those of the fluid flowing in the pipe; and the longitudinal tension of the chain represents in every particular the longitudinal tension on the pipe. As a simple form of this experiment, if a chain be set rotating at a very high velocity over a pulley, it will be seen that the centrifugal forces do not tend to disturb the path of the running chain; and, indeed, the velocity being extremely great, the forces, in fact, tend to preserve the path of the chain in opposition to any disturbing cause. On the other hand, if by sufficient force we disturb it from its path, it tends to retain the new figure which has been thus imposed upon it. The stream of fluid in the tortuous flexible pipe would behave in a strictly analogous manner.

[Here the author clearly illustrated his propositions by means of elaborate diagrams.]

As streams approach a body, their first act is to broaden, and consequently to lose velocity, and therefore, as we know, to increase in quasi-hydrostatic pressure. Presently they again begin to narrow, and therefore quicken, and diminish in pressure, until they pass the middle of the body, by which time they have become narrower than in their original undisturbed condition, and consequently have a greater velocity and less pressure than the undisturbed fluid. After passing the middle they broaden again until they become broader than in their original condition, and therefore have less velocity and greater pressure than the undisturbed fluid. Finally, as

they recede from the body they narrow again, until they ultimately resume their original dimension, velocity, and pressure. Thus, taking the pressure of the surrounding undisturbed fluid as a standard, we have an excess of pressure at both the head and stern ends of the body, and a defect of pressure along the middle.

We will now consider what will be the result of substituting an ocean of water for an ocean of perfect fluid. The difference between the behavior of water and that of the theoretically perfect fluid is twofold, as follows :—First. The particles of water, unlike those of a perfect fluid, exert a drag or fractional resistance upon the surface of the body as they glide along it. This action is commonly termed surface-friction, or skin-friction ; and it is so well-known a cause of resistance that I need not say anything further on this point, except this, that it constitutes almost the whole of the resistance experienced by bodies of tolerably easy shape traveling under water at any reasonable speed. Secondly. The mutual frictional resistance experienced by the particles of water in moving past one another, combined with the almost imperceptible degree of viscosity which water possesses, somewhat hinders the necessary stream-line motions, alters their nice adjustment of pressures and velocities, and thus defeats the balance of stream-like forces and induces resistance.

This action, however, is imperceptible in forms of fairly easy shape. On the other hand, angular or very blunt features entail considerable resistance from this cause, because the stream-line distortions are in such cases abrupt, and degenerate into eddies, thus causing great difference of velocity between adjacent particles of water, and great consequent friction between them. "Dead water," in the wake of a ship with a full run, is an instance of this detrimental action.

So far we have dealt with submerged bodies only ; we will now take the case of a ship traveling at the surface of the water. But first, let us suppose the surface of the water to be covered with a sheet of rigid ice, and the ship cut off level with her water-line, so as to travel beneath the ice, floating, however, exactly in the same position as before. As the ship travels along, the stream-like motions will be the same as for a submerged body, of which the ship may be regarded as the lower half ; and the ship will move without resistance, except that due to surface-friction and mutual friction of the particles. The stream-like motions being the same in character as those we have been considering, we shall still have at each end an excess of pressure which will tend to force up the sheet of ice, and along the side we shall have defect of pressure tending to suck down the sheet of ice. If, now, we remove the ice, the water will obviously rise in level at each end, so that excess of hydrostatic head may afford the necessary reaction against the excess of pressure ; and the water will sink by the sides, so that defect of hydrostatic head may afford reaction against the defect of pressure. The hills and valleys thus formed in the water are, in a sense, waves ; and, though originating in the stream-like forces of the body, yet when originated, they come under the dominion of the ordinary laws of wave-motion, and, to a large extent, behave as independent waves. The consequences which result from this necessity are most intricate ; but the final upshot of all the different actions which take place is plainly this—that the ship in its passage along the surface of the water has to be continually supplying the waste of an attendant system of waves, which from the nature of their constitution as independent waves, are continually diffusing and transmitting themselves into the surrounding water, or, where they form what is called broken water, crumbling away into froth. Now, waves represent energy, or work done ; and therefore all the energy represented by the waves wasted from the system attending the ship, is so much work done by the propellers or tow-ropes which are urging the ship. So much wave-energy wasted per mile of travel, is so much work done per mile ; and so much work done per mile is so much resistance. The actions involved in this cause of resistance, which is sometimes termed "Wave-genesis," are so complicated that no extensive theoretical treatment of the subject can be usefully attempted. All that can be known about this subject must, for the

present, I believe, be sought by direct experiment.

Having thus briefly described the several elements of a ship's resistance, I will proceed to draw your attention more particularly to certain resulting considerations of practical importance. Do not, however, suppose that I shall venture on dictating to shipbuilders what sort of ships they ought to build; I have so little experience of the practical requirements of ship-owners, that it would be presumptuous in me to do so; and I could not venture to condemn any feature in a ship as a mistake, when, for all I know, it may be justified by some practical object of which I am ignorant. For these reasons, if I imply that some particular element of form is better than some other, it will be with the simple object of illustrating the application of principles, by following which it would be possible to design a ship of given displacement to go at given speed, with minimum resistance, in smooth water—in fact, to make the best performance in a "measured mile" trial.

I have pointed out that the cause of resistance to the motion of a ship through the water are:—first, surface-friction; secondly, mutual friction of the particles of water (and this is only practically felt when there are features sufficiently abrupt to cause eddies); and thirdly, wave-genesis. I have also shown that these are the only causes of resistance. I have shown that a submerged body, such as a fish, or torpedo, traveling in a perfect fluid, would experience no resistance at all; that in water it experiences practically no resistance but that due to surface-friction and the action of eddies; and that a ship at the surface experiences no resistance in addition to that due to these two causes, except that due to the waves she makes. I have done my best to make this clear; but there is an idea that there exists a form of resistance, a something expressed by the term "direct head-resistance," which is independent of the above-mentioned causes. This idea is so largely prevalent, of such long standing, and at first sight so plausible, that I am anxious not to leave any misunderstanding on the point.

Lest, then, I should not have made my meaning sufficiently clear, I say distinctly, that the notion of head-resistance, in any ordinary sense of the word, or the notion of any opposing force due to the inertia of the water on the area of the ship's way, a force acting upon and measured by the area of midship section is, from beginning to end, an entire delusion. No such force acts at all, or can act. No doubt, if two ships are of precisely similar design, the area of midship section may be used as a measure of the resistance, because it is a measure of the size of the ship; and if the ships were similar in every respect, so also would the length of the bowsprit, or the height of the mast, be a measure of resistance, and for just the same reason. But it is an utter mistake to suppose that any part of a ship's resistance is a direct effect of the inertia of the water which has to be displaced from the area of the ship's way. Indirectly the inertia causes resistance to a ship at the surface, because the pressure due to it makes waves. But to a submerged body, or to the submerged portion of a ship traveling beneath rigid ice no resistance whatever will be caused by the inertia of the water which is pushed aside. And this means that, if we compare two such submerged bodies, or two such submerged portions of ships traveling beneath the ice, as long as they are both of sufficiently easy shape not to cause eddies, the one which will make the least resistance is the one which has the least skin surface, though it have twice or thrice the area of midship section of the other.

The resistance of a ship, then, practically consists of three items—namely, surface-friction, eddy-resistance, and wave-resistance. Of these the first-named is, at least in the case of large ships, much the largest item. In the *Greyhound*, a bluff ship of 1100 tons, only 170 feet long, and having a thick stem and sternposts, thus making considerable eddy-resistance, and at ten knots visibly making large waves, the surface-friction was 58 per cent. of the whole resistance at that speed; and there can be no doubt that with the long iron ships now built, it must be a far greater proportion than that. Moreover, the *Greyhound* was a coppered ship, and most of the work of our iron ships has to be done when they are rather foul, which necessarily increases the surface-friction item. The second item of re-

sistance, namely, the formation of eddies, is, I believe, imperceptible in ships as finely formed as most modern iron steamships. Thick square-shaped stems and stern-posts are the most fruitful source of this kind of resistance. The third item is wave-resistance. On this point, as we have seen, the stream-line theory rather suggests tendencies, than supplies quantitative results, because, though it indicates the nature of the forces in which the waves originate, the laws of such wave-combinations are so very intricate that they do not enable us to predict what waves will actually be formed under any given conditions.

There are, however, some rules, I will not call them principles, which have to some extent been confirmed by experiment. At a speed dependent on her length and form, a ship makes a very large wave-resistance. At a speed not much lower than this, the wave-resistance is considerably less, and at low speeds it is insignificant. Lengthening the entrance and run of a ship tends to decrease the wave-resistance; and it is better to have no parallel middle body, but to devote the entire length of the ship to the entrance and run, though in this case it be necessary to increase the midship section in order to get the same displacement in a given length. With a ship thus formed, with fair water-lines from end to end, the speed at which wave-resistance is accumulating most rapidly, is the speed of an ocean wave, the length of which, from crest to crest, is about that of the ship from end to end. I have said we may practically dismiss the item of eddy-resistance. The problem, then, to be solved in designing a ship of any given size, to go at a given speed with the least resistance, is to so form and proportion the ship that at the given speed the two main causes of resistance, namely, surface-friction and wave-resistance, when added together, may be a minimum. In order to reduce wave-resistance we should make the ship very long. On the other hand, to reduce the surface-friction we should make her comparatively short, so as to diminish the surface of wetted skin. Thus, as commonly happens in such problems, we are endeavoring to reconcile conflicting methods of improvement; and to work out the problem in any given case, we require to know actual quantities. We have sufficient general data from which the skin-resistance can be determined by simple calculation; but the data for determining wave-resistance must be obtained by direct experiments upon different forms to ascertain its value for each form. Such experiments should be directed to determine the wave-resistance of all varieties of water-line, cross section, and proportion of length, breadth and depth, so as to give the comparative results of different forms as well as the absolute result for each.

PINE TIMBER.*

By Mr. C. GRAHAM SMITH.

From "Engineering."

Wood, which not a great time back was one of the principal materials of construction, has now been replaced to so great an extent by iron, that timber does not receive the attention from engineering students which it did in the youth of our older members.

Excepting for foundation piles, small roofs, and railway platforms, it is seldom employed in this country for what may be termed permanent engineering structures. Still, as many of us students will probably be engaged on work in new countries, the development of which is, to a great extent, dependent on a proper employment of its resources among which timber generally occupies a position by no means unimportant, and as this material is so highly appreciated by the contractor for staging, temporary bridges, and other appliances necessary in the carrying out of large engineering contracts, the author trusts his remarks may prove of value.

Where speed in execution is the point above all others to be attained, timber, unless in exceptional cases, is the material to employ; for even in this country

* Read before the students of the Institution of Civil Engineers.

a wooden structure may be put up in the time occupied in rolling plates, and making templates for a more permanent one of iron.

Pine timber, one of the most abundant and useful of all woods, is found in one species or another nearly all over North America, and the countries bordering on, or in the vicinity of, the Baltic Sea.

Yellow, white, red and pitch pine, as also white and black spruce, are imported from North America; that from the Baltic is invariably known as fir timber, and is usually named after the district or country in which it is grown.

The yellow and white pines of America, although botanically different, are, in practice, looked upon as the same timber. It is not considered so durable as the Baltic fir when exposed to the weather in this country, but in its native land it seems to answer well; for the bridge over the Delaware at Trenton, was constructed with this timber in 1804, and the Pennsylvania Railroad Company have only now, seventy years after its erection, considered it advisable to replace it by an iron structure. A cargo of this timber will consist of balks varying in length from 20 ft. to 60 ft., and 40 to 80 cubic feet in content, the average scantling being about 16 in. by 16 in., and short logs may be had exceeding 26 in. by 26 in., but this is an exceptional size which commands a high price. If the balks composing a lot of this timber have an average content of 65 cubic feet, it may be bought at the market rate; and if 1½ per cent. be added for each 5 ft. above 65 ft. and up to 80 cubic feet, a very fair approximation to the value of the wood will be obtained. It is much in request for pattern making, and other purposes requiring a soft, non-resinous, and easily worked wood; and has a good quality of retaining its form when subjected to heavy working strains.

The red pine of America, so named from its color, is slightly harder than the yellow, and when exposed to damp is more durable. This, although an easily worked wood, is not used for such purposes as pattern making on account of its liability to twist and split, but when of good quality it is an excellent wood for masts and spars, being straight grained and tolerably free from knots. It is imported in balks up to 50 ft. in length, and generally about 40 cubic feet in content; the approximate extra value for each 5 ft. above this size is 1½ per cent. up to 50 cubic feet. The average scantling is 10 in. by 10 in., but it may be had in small quantities from 13 in. to 14 in. square.

Pitch pine, obtained from the Southern States of North America, is distinguished by the extremely large quantities of resin which it contains, and the distinctive character of its annual rings. In point of strength it is superior to yellow pine and Baltic fir to an extent of about 30 per cent., and is more durable than the former in positions subject to alternate wetness and dryness, but in a warm moist atmosphere it will very quickly rot; when totally immersed in water or buried underground it is supposed to be surpassed in durability by Baltic fir, although its use in these positions is of too recent a date for this to be borne out by experience. On account of the large amount of resin which this wood contains it will not take paint, neither is it considered a nice wood to work; for these reasons and on account of its dearness, it has not been much used excepting in the balk and by joiners for stairs and flooring boards. It is imported in balks averaging 16 in. × 16 in. and varying in length from 40 ft. to 70 ft. The market average is about 80 cubic feet, and the approximate extra value for each 5 ft. above this is 1½ per cent. up to 100 cubic feet; but special sizes up to 150 cubic feet may be obtained at high prices. There now being large quantities in the market its price is considerably reduced, and it is consequently coming very much more into use.

American white and black spruce, distinguished by the color of its bark, is a species of white wood which forms a good tough material for temporary work; but should not be used in permanent situations, as it shrinks, warps, cracks, and is very liable to rot when exposed to warmth or damp. This timber is imported in deals which are used for joists in inferior houses, also in balks varying from 30 cubic feet to 50 cubic feet in content, but more frequently in unbarked round logs, 9 in. to 12 in. in diameter at the butt, and varying in length from 20 ft. to 50 ft.; it is much used for ship

spars and other analogous purposes, in which case the bark is generally left on until the wood is cut up for use, this is said to preserve it from the rot and otherwise improve it; but when exposed to the weather it will not last more than five or six years unless kept properly painted or varnished.

Baltic fir contains no small quantity of resin and is somewhat similar in appearance and texture to pitch pine. It is slightly stronger, tougher, and when used in this country more durable than American yellow pine. The color of this wood is dependent on the climate and soil in which it is grown, and varies from light yellow to red, but when named by color considerable ambiguity is caused, as in England it is designated either red or yellow according to local custom. It is an excellent material when employed in dry and well ventilated situations, or when completely underground or water; still like most other woods it does not answer well in damp situations to which the air has access. Memel is considered to be the most durable of the whole pine class; balks of this timber as well as those from Riga, Sweden and Norway, do not much exceed 14 in. × 14 in. × 40 ft. in length, but this size may be obtained at the market rate. The timber from the north-western provinces of Prussia, may be had from 18 in. to 20 in. square and 50 ft. in length without much additional cost; but in order that there may be little sap wood and the logs be made as parallel as possible, it is usually cross cut into lengths varying from 20 ft. to 30 ft.

In newly sawn pine timber the sap and heart wood are generally very clearly defined; and when the balks are lying in the yard the quantity of sap wood may be roughly estimated in the early morning, as the dew will cause it to have a moist appearance whilst the more matured timber will be quite dry.

The Baltic spruce is not so tough as that obtained from America, but is generally considered to be more durable; still there is little choice between them, both being equally unfit for any permanent work unless thoroughly seasoned and kept perfectly dry, but not warm. This timber is largely imported from Norway, and being often 45 ft. or more in length and only 8 in. or 9 in. in diameter at its thickest part, is extensively used for scaffold poles, ladders and mine props.

In the building trade there are certain favorite scantlings for joists, planks, roof spars, and other portions of a structure; merchants, therefore, frequently ship a cargo of pine or spruce cut into planks, deals and battens of these sizes. Planks, deals and battens are usually 11 in., 9 in. and 7 in. in width respectively, by 2½ in. to 3 in. in thickness, and sometimes they are cut 4 in., but this is an exceptional size; although latterly many have been imported 6 in. thick and designated the "double deal." One great advantage to be derived from employing this foreign cut timber is that it is very much more seasoned than when imported in whole logs.

Many instance of wooden structures having stood centuries might be given, were it not well known that the durability of properly seasoned matured timber is beyond computation, when employed in those situations to which it is by nature adapted. Unfortunately the demand for timber is so great that it is felled at improper seasons, and consequently, on its arrival in this country, is often full of sap, and sometimes rot will be found to have set in; and this latter evil is not unfrequently propitiated after its arrival by its being stored on undrained waste ground fully exposed to the influence of this humid atmosphere, and so badly or closely piled that there is no ventilation whatever.

Trees for timber should be felled whilst the sap is not in circulation, that is a month or six weeks after they have begun to cast their foliage. Stripping the bark in the spring and felling the trees in the autumn or winter is stated by some authorities to harden the sap wood and make it firm and durable; whilst others consider this treatment to shorten the life of timber, and render it very liable to rot. These remarks do not apply to pine timber, as it is an evergreen, and the circulation of the sap is still a point to be decided by botanists; although practical men usually consider it to be less active during the winter months, when pine and fir are mostly felled; but so far as the author can learn this time is chosen merely on account of the convenience it affords for transport-

ing the timber to the banks of the freshets, sometimes a distance of 20 or 30 miles over marshy ground, which, unless frozen, would not sustain the weight of the horses.

In Australia the bushmen live in what are termed gunyahs; these are simply roughly formed huts covered with sheets of bark stripped from gum trees, the usual practice being to cut a ring of bark some 5 ft. or 6 ft. in height from the trunks of those trees nearest at hand; the tree dies, and the author can testify to the wood becoming hard and dry throughout in a very short space of time. This little piece of bush life has been introduced as giving matter for discussion, the process of "ringing" appearing to have, under some circumstances, sufficient merits to sanction its more extended application. If the bark be severed shortly after the leaves have begun to shoot they must depend for nourishment on the sap already within the tree, which, through the medium of the bark, will be more or less exhausted from all parts of the timber; whereas if the tree be stripped of its bark the wood will simply be dried by the influence of the atmosphere. This method will not answer with American pine, as the author has been informed that trees killed by this or other means, when left standing in that country, will, in the space of from 8 to 12 months, be full of worms, which seem to form directly under the bark.

Seasoning timber has from the earliest dates commanded much attention, and numerous methods have been proposed for superseding nature; among the principal of these are water seasoning, boiling and steaming. Water seasoning may be resorted to when dealing with small scantlings, but with large balks it is of little service, as the time occupied in penetrating to any depth is very considerable. Small timber treated in this way is not liable to warp or crack, the drying being carried on equally from the exterior to the interior; and as the timber is said to season more rapidly, timber ponds are considered by some to be necessary appendages to a timber yard. Most foreign pine wood undergoes this process to some extent, as when felled it is put into the freshets and carried by them to the rivers, where it is made into rafts sometimes four or five balks deep, and taken to a port for shipment, so being afloat from four to six months.

The time required for seasoning may be curtailed one-third by boiling or steaming, but this must not be carried to excess, or the strength and elasticity of the wood will be much reduced; it is not, therefore, considered advisable to continue the process longer than from 50 to 75 minutes for each inch in thickness, the exact time being determined by the nature of the wood. In shipbuilding this system is resorted to, as the timber when hot may be bent to almost any curve, and it is supposed to be a preventive against splitting, warping and the dry rot.

The generally accepted, although not fully determined, theory on which the success of these systems depends, is that the sap is dissolved, and thus a better circulation effected; and Mr. Sagismund Beer has found that this is greatly expedited by boiling the timber in a solution of borax, and afterwards washing it in hot water. Freshly imported timber of small size when treated by this process is fully shrunk, dried, and rendered, at the small cost of 4d. or 5d. per cubic foot, ready for use in the course of a few weeks; still it is to be feared that this method will not be found so efficacious when dealing with large scantlings, as the boiling is continued about six hours for each inch in thickness, whereby the elasticity of the exterior fibres of the timber must be impaired, and it is on these that the strength of wood mainly depends when used as struts and beams. It is said that these difficulties are got over by injecting the solution of borax under pressure, and as some experiments on large sizes of timber will probably be carried out under the author's supervision the results will be placed at the disposal of the Institution, even should these preconceived opinions prove erroneous.

Where time is not of first importance there is nothing like good dry fresh air for obtaining sound and durable timber; deals and planks are much sought after when seasoned under cover in this way.

The time occupied in seasoning timber depends so much on circumstances that it cannot be reduced to any rule of thumb; the same may be said of the weight lost during the process, which

varies with each species of timber and must not be taken at one-fifth or one-sixth as stated by some authorities; for instance pitch pine will not lose much more than one-fortieth of its weight, whilst English oak and yellow pine will sometimes be reduced as much as one-fourth.

Fresh air is also one of the best preventives against the rot; which is caused by the fermentation of the sap and is of two kinds. The "wet rot" caused by alternate wetness and dryness, and the "dry rot" by insufficient ventilation.

Many nostrums have been brought forward for its cure, but as they have proved of no practical use time will not now be taken up by referring to them; when once the rot sets in unless it be entirely cut away from the more sound timber the whole will be destroyed.

Nature in addition supplies other destroying elements, among which are sea-worms, and in tropical climates white ants, the latter of which have been known to honey-comb the sleepers at one end of a line of railway before the other was completed; but when the railway is once finished their ravages are at an end, for they will not attack timber subject to continuous vibration.

The most destructive sea-worms are the *Teredo navalis* and the *Limnoria terebans*; the former species, which is commonly known as the ship-worm, seems to be a development of the vegetation which attaches itself to timber, for it enters the wood by the smallest possible hole and remains therein, increasing in size as it proceeds; it is often found the length of one's finger, and it is said to have reached 3 ft. in length and $\frac{3}{4}$ in. in diameter. The latter species consists of small creatures seldom more than $\frac{1}{4}$ in. in length, still they do fully as much mischief as their larger companions. From the experiments of Mr. Stevenson at the "Bell Rock," it would appear that all kinds of pine wood are completely destroyed by the *Limnora terebans* in periods of time varying from one and a half to four and a half years.

"Kyanizing," "Burnetizing," "Creosoting," and other methods have been adopted for preserving timber; but as creosoting is now generally employed, to the exclusion of the other more expensive processes, in most situations not especially liable to fire or where its odor is not objectionable, it will alone here be considered. Timber to be creosoted is put into large iron cylinders in which a vacuum is maintained for a period governed by the quality, scantling and condition of the wood; by this means the sap is withdrawn, when its place is supplied by creosote, extracted from coal tar, in which it exists to the extent of from 20 to 23 per cent.; this is forced into the pores of the timber under a pressure of from 100 lb. to 180 lb. per square inch. Yellow pine may be impregnated with 12 or more pounds of creosote per cubic foot, but 10 lb. is the quantity usually specified; and in order to get thorough work all timber should be weighed both before and after the operation. Nominal creosoting is practiced to no little extent; the vacuum is often left on for too short a time, or perhaps not put on at all, the wood is consequently creosoted only $\frac{1}{4}$ in., or an inch in depth from the surface; and should it not be properly seasoned, sap is confined to the interior and the wood rendered most liable to decay. This has in fact much the same effect as painting, smoking, or charring, none of which should be resorted to until the wood is thoroughly seasoned; it is often desirable to leave posts or framed structures exposed to the weather for a year or more before painting them. Creosoting pine timber with 10 lb. per cubic foot costs, without including wear and tear of plant, about $5\frac{1}{2}$d. per cubic foot; it reduces its transverse strength fully one-eighth, but at the same time renders it very durable and protects it to a great extent against the white ant and sea-worms; but for what length of time timber thus prepared will stand the attacks of the latter, has not yet been definitely determined. Mr. Stevenson states that at Invergordon and other places the worm eats freely thoroughly creosoted timber; but at Ostend creosoted timber was at the end of seven years untouched, whilst that uncreosoted, but otherwise under precisely similar circumstances, was completely perforated by the *Teredo* in two years; and many like instances might be given. Mr. Rendal, in giving evidence before the Leith Harbor Commissioners, limits the life of creosoted timber submerged in that port to 20 years;

if this be so a step in the right direction has been made, for Mr. Stevenson found that the *Limnoria terebans* began to attack even greenheart when submerged nineteen years; and at Wick Harbor and Salem in the Sound of Mull this timber was found to be attacked after being submerged only four years.

Galileo was among the first to investigate the strength of wooden beams on purely mathematical principles; and, like many later investigators, after employing the higher mathematics to an unlimited extent, arrived at conclusions incompatible with practice. To use Tredgold's words, "fortunately that precision so essential to the philosopher is not absolutely necessary to the architect and engineer," consequently simple formulæ, such as $W = C\frac{b\,d^2}{L}$, may be resorted to in practice. These formulæ are generally deduced from actual experiment in the manner somewhat as follows: If a beam of b inches in breadth, d inches in depth, and L feet clear span, breaks with a weight W in cwts. applied at the centre, it is not difficult to determine in what ratio the strength of another beam of the same material will vary; if the breadth be double it is at once evident that its strength is doubled, if its length be double its strength is practically halved, and if its depth be double its strength will be increased four times; for these reasons the sectional areas in tension and compression, as well as the distance apart of their centres of gravity are doubled, consequently the moment of resistance of the beam is increased four times, and similarly by using any other depth it will be found that this moment varies as the square of the depth. The breaking weight, therefore, varies directly as the breadth and square of the depth, and inversely as the length, therefore $W \propto \frac{b\,d^2}{L}$. Now it is well known that the adhesion of the particles or fibres to one another affect the strength of a beam, to an extent which can only be determined by introducing an unknown quantity; W therefore becomes equal to $C\frac{b\,d^2}{L}$, where C is the unknown, but nearly constant, quantity, the value of which can be ascertained only by actual experiment. But since the strengths of no two beams of the same timber and scantlings are precisely the same, it follows that no two constants will be equal in value; this accounts, to some extent, for the variety of scantlings employed for one and the same purpose. A short time since a warehouse floor gave way, and the engineers employed on opposite sides of the law action which ensued had little difficulty, by using the extremes of constants, in making their calculations suit the wishes of their respective clients. The floor was thus shown on good authority to be at the same time both amply strong and too weak; under these circumstances the only course to pursue was to call in an independent witness, who not being content to accept a constant which might at any time be disputed, had a beam from the floor in question tested, deduced a constant from the result, and gave his evidence accordingly. As the quality of timber varies very considerably, even in the same cargo, before employing it in work of any magnitude, one or more average samples should be tested, and a constant deduced on which all calculations for the strength of the timber may be based, This method is pursued by Mr. Lyster. engineer-in-chief to the Mersey Docks, and Harbor Board; and as it has been his practice for many years past, he is now in possession of some very valuable results, a few of which, by his kind permission, are put before you in the Addenda.

The experiments given have been selected on account of their being, so far as the author can learn, the largest scantlings ever tested. The constants of Tredgold, Barlow, and others were obtained by testing small pieces of timber, in selecting which it has evidently gone against the conscience of the investigators to take those cross-grained and containing knots; but timber of any size has always more or less of these blemishes, consequently their constants give a strength to timber which cannot be attained in actual work. On referring to the Addenda it will be found that (Experiment No I.) a best selected Memel fir beam 13½ in. by 13½ in. with 10 ft. 6 in. clear span practically gave way with a distributed load of 56 tons,

and finally broke down with 61 tons; whilst the distributing breaking weight of this beam found by employing the constant for Memel given by Tredgold is 114 tons, and by that of Barlow 120 tons; similar results will be obtained if the remaining experiments be compared with the same or other authorities.

Constants deduced from testing large pieces of timber will be found in the Addenda, and it is the author's opinion that these will give results approximating very closely to ordinary practice; should this meeting take a similar view there will be little difficulty in deducing from them other constants for beams loaded or supported in any way whatever; or even for columns which are of such proportions that they give way wholly by flexure.

The deflection of timber which is to be used in a permanent structure need hardly be considered, so long as factors of safety of eight or ten are adhered to, for up to one-fifth of the breaking load it is certainly not excessive.

In conclusion it may be well to state that the author has based his remarks mostly on experience gained whilst studying under Mr. Lyster; and he hopes they will harmonize with those of his fellow-students.

Addenda.

The accuracy of the following results is beyond question; for the experiments were carried out in accordance with instruction from the engineer to the Mersey Dock Board under the supervision of the resident engineer at Birkenhead.

The tests by hydraulic machinery were made at the Birkenhead Chain Test Works belonging to the Dock Board. This machinery is so arranged that it is checked by three separate and independent appliances, all of which were accurately adjusted. Firstly, by a lever and dial, the lever being actuated by a small metal ram worked direct from the pressure on the cylinders of the strain being registered on the dial. Secondly, by dead weights lifted by a small ram which is also worked direct from the pressure in the cylinders. And lastly, by dead weighted levers working on knife edge centres up to 100 tons. The machinery was constructed by Sir William Armstrong and Co.'s and is fully up to their usual standard of workmanship.

The constants deduced or given are intended to be employed in the formula $W=\frac{C\,b\,d^2}{L}$ where W = the breaking weight at centre in cwts., b=breadth in inches, d=depth in inches, and L=clear span.

No. I.

Experiment with two best selected Memel fir beams 13½ in. wide, 13½ in. deep, and 10 ft. 6 in. clear span. Both beams were cut from the same balk and placed 12 ft. apart centre to centre, the space between them being bridged with railway metals, upon which pig iron was loaded until the beams broke.

The following observations were taken:

Load Distributed on the Two Beams.	Deflection.		Remarks.
	Beam cut from Butt.	Beam cut from Top.	
Tons.	In.	In.	
40.2	.10	.12	
59.6	.31	.27	
75.2	.37	.51	
97.3	1.12	1.45	First fracture observed.
111.7	..	..	The deflection not taken as the beams had crushed at ends.
122.0	Broke.	Broke.	

The distributed breaking load on each of the above beams is, therefore, $\frac{122}{2}=61$ tons, which is equivalent to 30.5 tons applied at the centre.

$$C=\frac{W\,L}{b\,d^2}$$

$$=\frac{30.5\times20\times10.5}{13.5\times13.5\times13.5}=\frac{6405}{2460}$$

Therefore C=2.60.

No. II.

Experiment with two Quebec yellow pine beams 14 in. wide, 15 in. deep, and 10 ft. 6 in. clear space. Both beams were cut from the same log and tested in precisely the same manner as No. I.

The following observations were taken:

SUMMARY OF TIMBER EXPERIMENTS NOS. I. TO V.

Species of Timber.	Scantling.	Clear Span.	Number of Beams Tested.	Average Break-load applied at Centre.	Average valve of C in $W = C\frac{bd^2}{L}$.	Remarks.
	In. In.	Ft. In.		Tons.		
Baltic Memel fir.....	$13\frac{1}{2} \times 13\frac{1}{2}$	10 6	2	30.50	2.60	Distributed Load.
Quebec yellow pine..	14 × 15	10 6	2	30.50	2.03	" "
Baltic fir (average)...	6 × 12	12 3	2	9.50	2.70	Load applied at centre by means of hydraulic machinery.
Pitch pine.....	6 × 12	12 3	2	10.35	2.93	
American red pine...	6 × 12	12 3	2	8.00	2.27	
Pitch pine.....	14 × 15	10 6	2	60.00	4.00	
Quebec yellow pine..	14 × 15	10 6	2	36.00	2.40	

Load Distributed on the Two Beams.	Deflection. Practically the same on both Beams.	Remarks.
Tons.	Inches.	
26.6	.18	
57.0	.29	
69.6	.39	
83.0	.66	
102.0	.87	First fracture observ'd
122.0	Broke.	

The beam cut from the top end of the log broke down bodily.

The distributed breaking load on each of the beams is, therefore, $\frac{122}{2} = 61$ tons, which is equivalent to 30.5 tons applied at the centre.

$$C = \frac{W L}{b d^2}$$

$$= \frac{30.5 \times 20 \times 10.5}{14 \times 15 \times 15} = \frac{6404}{3150}$$

Therefore C = 2.03.

No. III.

Experiment to ascertain the relative strength of Baltic fir, pitch pine, and American red pine. Beams 6 in. wide, 12 in. deep, and 12 ft. 3 in. clear bearing. The ends of the logs were placed in stirrups, and the load applied at the centre by means of hydraulic machinery.

The following observations were taken:

Load applied at Centre.	Baltic Fir. Deflection.		Pitch Pine. Deflection.		Red Pine. Deflection.	
	Sample No. 1.	Sample No. 2.	Sample No. 1.	Sample No. 2.	Sample No. 1.	Sample No. 2.
Tons	In.	In.	In.	In.	In.	In.
3.0	.29	.37	.11	.38	.43	.37
5.0	.56	.60	.28	.61	.70	.61
7.5	..	..	..	..	Broke	
8.0	.87	1.11	.53	.97	..	1.94
8.5	Broke	..	..	..	..	Broke
10.0	..	1.93	.78	1.31		
10.2	..	..	Broke			
10.5	..	Broke	..	Broke		

Baltic Fir.—Average breaking weight applied at centre

$$= \frac{8.5 + 10.5}{2} = 9.5 \text{ tons.} \quad C = \frac{W L}{b d^2}$$

Therefore

$$C = \frac{9.5 \times 20 \times 12.25}{6 \times 12 \times 12} = \frac{2327}{864} = 2.70.$$

Pitch Pine.—Average breaking weight applied at centre

$$= \frac{10.2 + 10.5}{2} = 10.35 \text{ tons.}$$

Therefore

$$C = \frac{10.35 \times 20 \times 12.25}{6 \times 12 \times 12} = \frac{2536}{864} = 2.93.$$

American Red Pine.—Average breaking weight applied at centre

$$\frac{7.5 + 8.5}{2} = 8 \text{ tons.}$$

Therefore $C=\frac{8\times20\times12.25}{6\times12\times12}=\frac{1960}{864}=2.27$.

No. IV.

Experiment with two pitch pine beams cut from the same log 14 in. wide, 15 in. deep, and 10 ft. 6 in. clear bearing. Tested by hydraulic machinery in the same manner as No. III.

The following observations were taken:

Load applied at Centre.	Deflection.		Remarks.
	Beam cut from Butt.	Beam cut from Top.	
Tons.	Inches.	Inches.	
10.0	.02	.05	
20.0	.22	.27	
30.0	.36	.41	
40.0	.49	.61	
50.0	.72	.93	
59.2	..	Broke.	
60.0	1.14		

In testing the beam cut from the butt of the log, the strain was slacked off at 60 tons, and on account of being again put on rather too suddenly the beam broke with 57.5 tons, but there can be very little doubt but that 60 tons is very near the breaking weight of the specimen.

$$C=\frac{W\,L}{b\,d^2}$$

$$=\frac{60\times20\times10.5}{14\times15\times15}=\frac{12,600}{3150}$$

Therefore $C=4$.

No. V.

Experiment with two Quebec yellow pine beams, cut from different logs, 14 in. wide, 15 in. deep, and 10 ft. 6 in. clear span. Tested by hydraulic machinery in the same manner as No. III.

The following observations were taken:

Load applied at centre.	Deflection.		Remarks.
	Sample No. 1.	Sample No. 2.	
Tons.	Inches.		Deflection of sample No. 2 not taken.
10.0	.14		
20.0	.44		
30.0	.56		
34.0	..	Broke.	
38.3	Broke.		

Average breaking weight applied at centre

$$=\frac{38.3+34}{2}=36 \text{ tons.}$$

$$C=\frac{W\,L}{b\,d^2}$$

$$=\frac{36\times20\times10.5}{14\times15\times15}=\frac{7560}{3150}$$

Therefore $C=2.40$.

From a careful study of many experiments on both large and small scantlings of timber, and taking into consideration that sap wood is generally more or less present in most beams, the author would advise that the following constants be employed in ordinary work: Baltic fir when of best quality 2.6, when second rate 2.3; Canadian yellow pine 2.2; pitch pine 2.4; and American red pine 2.3.

TELFORD AND MACADAM ROADWAY PAVEMENT.

By A. P. STORRS, Jr., C. E.

Written for Van Nostrand's Engineering Magazine.

In the construction of a Telford and Macadam Roadway Pavement, the first consideration must be given to the selection of the materials which are to be used. This is a question of the greatest importance, for with poor materials it is impossible to construct a good and durable pavement. The location of the proposed work must decide which of the different materials of which it is proper to construct such a pavement may be used. The hardest and most durable rock that can be procured without too large an expense is always the most desirable.

MATERIALS.

For the "Telford" foundation, any

rock which is not too easily crushed or decomposed by the action of water, may be used. Of those which are found most common, trap rock and gneiss are the best adapted to this use; they are easily sledged to the required shape and size, and are very durable. A few weeks since, a Telford pavement of this material, which had been in use for five years, was examined, and not the least signs of decomposition could be discovered.

For broken stone, or Macadam, or road metal, as it is sometimes called, a *hard* and *tough* material is required, such as green stone, trap rock, hard lime stone, or slag from iron furnaces.

For the surfacing or binding of the Macadam, clean sharp gravel or the screenings of the broken stone may be used. The latter can be surfaced with less rolling, and retains moisture for a longer time when sprinkled, and, therefore, has the preference.

CROSS SECTION.

Before the materials selected for the pavement can be prepared, the *cross section* of the pavement must be decided upon. This must be governed by the kind and amount of traffic it is required to carry. If this is constant and heavy, a thick pavement is reqired; if there is to be but little travel over it, as upon a country road, a much thinner pavement will be all that is necessary.

For city use, where the traffic is heavy, a Telford foundation 8 inches in thickness is laid, and covered with 10 inches of broken stone. Telford, on the Holyhead roads in England, laid upon a level road had a foundation of from 4 to 7 inches in thickness, placing the smaller stones at the side or gutter, and the larger ones in the centre, thus giving the surface a crown from the gutter to the centre. In Germany, upon the Government roads, the foundation is laid from 8 to 12 inches in thickness, and when the pavement is laid across marsh lands, two courses of foundation are laid, one upon the other, each of them 12 inches in thickness, and upon this the road metal is placed.

For an ordinary highway or turnpike, a Telford foundation 6 inches thick, with 6 inches of Macadam upon it, thoroughly rolled and surfaced, affords a perfect protection to the road bed, and is therefore all that is required.

In all cases, whatever may be the thickness of the pavement laid, the surface must be so formed, that the water falling upon it will run to either side, when it will be conducted by the gutter to the side drains or sewers, and by them removed from the road. If this crown is too great, the water flowing across the pavement rapidly will form gutters and destroy the surface; this must be carefully avoided. A crown of 1 in 60 for a pavement over 60 feet in width, and 1 in 30 for one of less width, will be found suitable. Upon a steep grade a *larger crown* is required than upon a light one, to prevent the surface water from flowing too far down the grade and over the surface of the road, before reaching the gutter. The crown should take the form of the arc of a circle. Experience has shown, that when the surface of a pavement is made to pitch in a straight line from the centre of the roadway to either gutter, that passing vehicles are inclined to keep near the gutter, and by constant use this portion of the road is worn down more rapidly than the rest, and a hollow is formed in the surface which retains the water, and prevents it from flowing into the gutter; and causes it to take a new channel for itself in the roadway.

ROAD BED.

Like any other structure, a pavement must have a firm foundation upon which to rest, or it will be worthless. The road bed must be carefully prepared; all rock must be removed to a sufficient depth to allow 6 inches of earth between it and the Telford. All boulders which appear on the surface must be removed, and the holes thus made filled with earth and well rammed. Any soft loam or decayed vegetable matter should be replaced by good firm material. The road bed should be shaped to the crown which the pavement will have when completed, and the whole surface well rolled with an iron road roller, of not less than two tons in weight, drawn by horses.

Care must be taken to drain the road bed thoroughly, so that neither natural springs nor surface water shall cause the earth of which it is formed to become soft or spongy. The road bed should be

raised from 2 to 4 inches above the required grade (after making allowance for the thickness of the pavement) to allow for settlement caused by the heavy rollers, with which the Macadam is rolled, forcing the Telford into the road bed, and the packing of the materials of which it is formed.

TELFORD FOUNDATION.

Upon the road bed is laid the Telford foundation. This may be constructed of any good firm rock, which may be convenient to the work and easily procured. The material used in New York City for this purpose is gneiss rock, which is found in large quantities upon the island. Its abundance and consequent cheapness recommend it; and experience has proved it to be equal to any kind of stone for a foundation. Care is taken to select a quality that does not contain too much mica, and which is firm and sound.

The rock which has been selected for the foundation or "Telford," is broken with sledges to the required size. The rule is that the stones should have a base of not more than 80 or less than 12 square inches, and a depth of a little more than the required thickness of the foundation when completed. These stones are set in courses with their bases on the road bed and their greatest length extending across, and at right angles to the centre line of the road. The ends of each stone are clipped square so as to present as great a surface as possible to the adjoining stones, in order to form as strong a bond as possible. Each course must be laid so as to break joints with the one laid before it; the stones must be set plumb, rather than at right angles to the grade line; this is done so that the weight of passing vehicles may be received and transferred to the road bed, without forcing the stones from their positions.

The pavement is then thoroughly wedged by forcing small pieces of stone into all the interstices. This is done with an iron bar about 4 feet long and 1¼ inch in diameter, which is furnished with a wedge shape point, and a round flat head about 2½ inches in diameter. With the point of the bar the stones are forced apart, and into the spaces thus formed smaller stones are driven with the head of the bar. When this wedging is done thoroughly, a good foundation for the Macadam is secured. Any projecting points are then removed from the surface of the "Telford," by breaking them off with a small hand hammer; this is called clipping. Any loose stone remaining upon the surface, are either removed or broken to about the size of the Macadam, which is to be placed upon the road.

The object of this foundation is twofold. 1st, It is the means of distributing the weight or pressure which is applied to the surface of the road, over a large area of road bed, and thus preventing any possibility of the pavement sinking and becoming uneven. 2d, It serves as a drain for any water that would otherwise collect under the pavement, and prevents it from softening or otherwise injuring the road bed.

MACADAM OR ROAD METAL.

This "Telford foundation" is covered with broken stone, called "Macadam" or "road metal," to a thickness of from 6 to 12 inches. This course receives all of the wear caused by the traffic, and defective construction here will increase very largely the amount of labor and materials required to keep the road in repair, and the greatest care must be exercised in the selection of the material and the manner in which they are applied. The road metal must be made of a tough and hard substance. Basaltic and trap rocks, and especially those which contain a large percentage of hornblende are the best.

Neither granite, nor any rock which contains quartz, feldspar or mica, in any considerable quantities, should be used. They are easily crushed, and such as contain feldspar are soon decomposed by the action of the weather.

The greater the specific gravity, the firmer the grain, and in trap rocks, the more decidedly blue the color, the tougher and more durable is the rock.

When trap rock has a coarse grain and is of a brownish color, it will crush easily, and decay when exposed to the action of the weather. More or less of this material is found upon the surface of all beds of trap rock, but should never be used for metaling a road.

The rock selected is broken by hand or machine to the required size. In this

city the specifications are as follows:

"The stone to be of trap rock, of a sound, hard and durable quality, entirely free from soft, disintegrated, or other stone that can be easily crushed, to be broken to a uniform size, so as to pass through a ring of from 1½ inches to 2 inches in diameter, and to be screened free from dust and dirt."

Macadam required that "all stones should be broken by hand into angular fragments." When a large quantity of stone is to be used, it is almost impossible to get it broken by hand to the required size as rapidly as it is wanted.

To make it profitable, the men employed must be paid by the yard, and in order to increase their wages they will leave the stone too large. Nearly all of the broken stone used in this city, is broken from the spawls taken from the "Trap Block" quarries on the west of the Hudson River opposite the city.

Machines now in use, known as the "Improved Blake Crushers," break the rock into "angular fragments" sufficiently uniform, and to any desired size.

Hand broken stone require less rolling to pack them than machine broken stone, but when once packed they make equally durable pavements.

All hand broken stones should be handled with forks made for the purpose, before they are placed upon the road, in order to free them from dirt and dust.

Machine broken stones should be passed over a scum to separate from them all dust and fine stone, which is formed in the breaking. This fine material or "scummings" may be used to advantage for the binding or surfacing of the road.

The broken stone is spread upon the Telford foundation in two layers or courses of from 3 to 6 inches in thickness. The first layer is rolled until it ceases to settle, and is firm as the roller passes over it. The second layer is then added and rolled until it presents a smooth surface.

On the first Telford and Macadamized roads built in this city, broken stone of gneiss was used for the first layer, but it proved to be as expensive as trap, and was much inferior to it. When the second layer was rolled the soft stone beneath would crush to a powder. The use of it has since been discontinued.

Two layers of broken trap, each 6 inches in thickness, make, when rolled, nearly a solid mass 10 inches in thickness, making with the Telford foundation, as laid in New York, a pavement 18 inches in thickness, which is nearly impervious to water, and is not disturbed by frost. The frost often penetrates the earth for some distance below the bottom of the pavement, but it never heaves it.

During the present winter (1874 and 1875), I made an examination of a number of different pieces of this pavement, and found in every case that the frost had penetrated the road bed for a depth of from 9 to 18 inches, and that the interstices in the Telford foundation were filled with ice, but in not a single instance was the pavement disturbed by the frost coming out of the ground.

The rolling of the broken stone, and the furnishing of the surface, is done with heavy iron rollers moved by either steam or horse-power.

A sufficient number of sprinkling carts are provided to keep the stones thoroughly wet during the process of rolling. This causes them to pack more rapidly than when they are dry.

SURFACING AND ROLLING.

When the second layer of broken stone has been rolled so that it presents a smooth surface, *it is thoroughly wet*, and a thin layer, about one-half an inch in thickness of clean sharp gravel, or what is preferable, screenings and clips of trap rock, is spread over it, and rolled, a second layer is spread of the same material, and so on, until the water from the carts ceases to penetrate the pavement, but is held up on the surface, or, in other words, the surface is "puddled."

During all of this process of rolling, the pavement must be kept thoroughly saturated with water. When the surface is puddled the heavy rollers are removed, and a road roller, weighing two tons, which is drawn by horses, keeps the surface smooth until it is thoroughly dry. The road is then ready to be thrown open to traffic.

Where the grades are not greater than 1 in 15, steam rollers made by Aveling & Porter, England, are generally used on the city work—these weigh about 15 tons. On any grade over 1 in 15, large

iron rollers, weighing about 8 tons, and drawn by 8 horses, are used.

DRAINING.

Drains or receiving basins should be built at a distance of not more than 300 feet apart, to take the water which is collected in the gutters away from the road.

When this cannot be done, and the water has to be carried a greater distance by the gutter, or when the grade is greater than 1 in 40, concrete gutters should be laid. For this purpose, 1 part cement, 2 parts clean sharp sand, and 6 parts clean broken stone, are mixed together. Sufficient water is then added to bring the mass to a proper consistency.

The Macadam is removed for a distance of 2 feet from the curb, to a depth of 6 inches, the trench thus formed is thoroughly wet, and filled with the concrete, which is settled with a wooden rammer until it is flushed. This forms a gutter which cannot be washed away by the water, and adds but a very small amount to the cost of the road, and will save a great deal both in maintenance and repairs.

When no curb is laid at the sides of the roadway, a gutter made of trap block or cobble stones is desirable, this prevents any portion of the pavement from working out to the sides of the road.

MAINTENANCE.

A Telford and Macadam road must be properly "maintained" or "kept up." If this is done thoroughly from the start the cost of repairs of the road will be very much reduced. In fact, a road that is well and thoroughly maintained, needs very little repairing, for it is never out of order.

Fresh materials must be added in small quantities, as they are needed, to keep the road to its proper cross section. Any small holes, ruts, loose stone, or other imperfections must be filled or removed; this requires the constant care of industrious and trusty men.

A road should be divided into sections of not more than a quarter of a mile in length. At or about the centre of each section should be a small quantity of broken stone and gravel, to be used as it is required upon the section; and also a place where all droppings, or other material taken from the surface of the road, may be deposited.

One man can take care of from four to twelve such sections. The number depends upon the width of the road and the amount of traffic over it.

When a pavement is new, small stones will "prick up." These must be removed, and the hole formed filled with gravel. Any accumulation of mud or dust must be removed by scraping. This can be done just after a shower, when the road is wet, to the best advantage. The road must not be scraped too clean, a covering of $\frac{1}{4}$ inch in thickness of the dust which is formed by the wear of the road metal protects the surface of the pavement, and when it is kept moist, as it should be, makes the road smoother for the passing vehicles, and less trying to the horses driven over it.

When the stones of which the pavement is composed become bare, a very thin layer of clean sharp gravel should be spread over it. It is not necessary to roll this, the wheels of passing vehicles soon form it into a smooth surface. When it becomes necessary to raise the road, to its original cross section, the surface should be "raised" with short picks, so that new material placed upon it will when rolled form a perfect bond with the old material.

The rolling is best done with heavy rollers, but if these are not convenient, the action of the wheels passing over the thin coat of stone will in time serve the same purpose. The surface of the road must be kept moist, but not wet, if it becomes too dry the stones lose their bond, and the road becomes rough; and too much water will soften the surface, and in time will form ruts. Both of these evils must be carefully avoided.

The following data are the result of careful experiments, and will be of great value and convenience in making estimates for, or in the construction and maintenance of, a Telford and Macadamized roadway pavement:

One man's labor for 10 hours is equivalent to the following items:

2 cubic yards of stone sledged for Telford pavement.

8 cubic yards of stone loaded and unloaded from wagon.

35 square yards 8 in. Telford pavement laid.
31 square yards 8 in. Telford pavement wedged.
60 square yards 8 in. Telford pavement clipped.
1½ to 2 cubic yards trap rock broken from quarry spawls.
16 cubic yards broken stone or gravel spread on road.

A gang of men for paving Telford pavement should be devised as follows :

1 man paving to every 6 ft. in width of pavement.
1 man wedging to every 5 ft. in width of pavement.
1 man clipping to every 10 feet in width of pavement.

A steam roller requires

1 steam engineer.
1 laborer or wheelman.
1 water cart.
1 watchman.

Aveling & Porter's 15 ton road roller will consume per day :

⅛ to ½ ton of coal.
⅒ gal. oil.
⅒ lbs. cotton waste.

Will roll and finish 151 square yards pavement.

Each steam roller should be attended by :

2 sprinkling carts.
3 road men to keep the surface of the road to the required shape, and to spread gravel.

Maintenance :

1 2-horse monitor will sprinkle in the city, when water is convenient, 32,000 square yards road.
1 1-horse cart will sprinkle 14,000 square yards.
1 man will keep 30,000 square yards of pavement free from stones and droppings where the travel is constant.

THE ORIGIN AND GROWTH OF ENGINEERING SCIENCE.

Inaugural Address of Sir JOHN HAWKSHAW, F. R. S., before the British Association.

Condensed from report in "Nature."

To those on whom the British Association confers the honor of presiding over its meetings, the choice of a subject presents some difficulty.

The Presidents of Sections, at each annual meeting, give an account of what is new in their respective departments ; and essays on science in general, though desirable and interesting in the earlier years of the Association, would be less appropriate.

Past Presidents have already discoursed on many subjects, on things organic and inorganic, on the mind and on things perhaps beyond the reach of mind, and I have arrived at the conclusion that humbler themes will not be out of place on this occasion.

I propose in this Address to say something of a profession to which my lifetime has been devoted—a theme which cannot perhaps be expected to stand as high in your estimation as in my own, and I may have some difficulty in making it interesting ; but I have chosen it because it is a subject I ought to understand better than any other. I propose to say something on its origin, its work, and kindred topics.

Rapid as has been the growth of knowledge and skill as applied to the art of the engineer during the last century, we must, if we would trace its origin, seek far back among the earliest evidences of civilization.

In early times, when settled communities were few and isolated, the opportunities for the interchange of knowledge were scanty or wanting altogether. Often the slowly accumulated results of the experience of the wisest heads and the most skillful hands of a community were lost on its downfall. Inventions of one period were lost and found again. Many a patient investigator has puzzled his brain in trying to solve a problem which had yielded to a more fortunate

laborer in the same field some centuries before.

The ancient Egyptians had a knowledge of Metallurgy, much of which was lost during the years of decline which followed the golden age of their civilization. The art of casting bronze over iron was known to the Assyrians, though it has only lately been introduced into modern metallurgy; and patents were granted in 1609 for processes connected with the manufacture of glass, which had been practised centuries before. An inventor in the reign of Tiberius devised a method of producing flexible glass, but the manufactory of the artist was totally destroyed, we are told, in order to prevent the manufacture of copper, silver, and gold from becoming depreciated.

Again and again engineers as well as others have made mistakes from not knowing what those had done who have gone before them, and have had the same difficulties to contend with. In the long discussion which took place as to the practicability of making the Suez Canal, an early objection was brought against it that there was a difference of 32½ feet between the level of the Red Sea and that of the Mediterranean. Laplace at once declared that such could not be the case, for the mean level of the sea was the same on all parts of the globe. Centuries before the time of Laplace the same objection had been raised against a project for joining the waters of these two seas. According to the old Greek and Roman historians, it was a fear of flooding Egypt with the waters of the Red Sea that made Darius, and in later times again Ptolemy, hesitate to open the canal between Suez and the Nile. Yet this canal was made, and was in use some centuries before the time of Darius.

Strabo tells us that the same objection that the adjoining seas were of different levels, was made by his engineers to Demetrius, who wished to cut a canal through the Isthmus of Corinth some two thousand years ago. But Strabo dismisses at once this idea of a difference of level, agreeing with Archimedes that the force of gravity spreads the sea equally over the earth.

When knowledge in its higher branches was confined to a few, those who possessed it were often called upon to perform many and various services for the communities to which they belonged; and we find mathematicians and astronomers, painters and sculptors, and priests called upon to perform the duties which now pertain to the profession of the architect and the engineer. And as soon as civilization had advanced so far as to admit of the accumulation of wealth and power, then kings and rulers sought to add to their glory while living by the erection of magnificent dwelling-places, and to provide for their aggrandizement after death by the construction of costly tombs and temples. Accordingly we soon find men of ability and learning devoting a great part of their time to building and architecture, and the post of architect became one of honor and profit. In one of the most ancient quarries of Egypt a royal high architect of the dynasty of the Psammetici has left his pedigree sculptured on the rock, extending back for twenty-three generations, all of whom held the same post in succession in connection with considerable sacerdotal offices.

As there were in these remote times officers whose duty it was to design and construct, so also there were those whose duty it was to maintain and repair the royal palaces and temples. In Assyria, 700 years before our era, as we know from a tablet found in the palace of Sennacherib by Mr. Smith, there was an officer whose title was the Master of works. The tablet I allude to is inscribed with a petition to the king from an officer in charge of a palace, requesting that the master of works may be sent to attend to some repairs which were much needed at the time.

Under the Roman Empire there was almost as great a division of labor in connection with building and design as now exists. The great works of that period were executed and maintained by an army of officers and workmen, who had special duties assigned to each of them.

Passing by those early attempts at design and construction which supplied the mere wants of the individual and the household, it is to the East that we must turn if we would find the earliest works which display a knowledge of

engineering. Whether the knowledge of Engineering, if we may so call it, possessed by the people of Chaldæa and Babylonia was of native growth or was borrowed from Egypt is, perhaps, a question which cannot yet be answered. Both people were agricultural, dwelling on fertile plains, intersected by great rivers, with a soil requiring water only to enable it to bring forth inexhaustible crops. Similar circumstances would create similar wants, and stimulate to action similar faculties to satisfy them. Apart from the question of priority of knowledge, we know that at a very early period, some four or five thousand years ago at least, there were men in Mesopotamia and Egypt who possessed considerable mechanical knowledge, and no little skill in hydraulic engineering. Of the men themselves we know little; happily, works often remain when the names of those who conceived and executed them have long been forgotten.

It has been said that architecture had its origin not only in nature, but in religion; and if we regard the earliest works which required mechanical knowledge and skill, the same may be said of engineering. The largest stones were chosen for sacred buildings, that they might be more enduring as well as more imposing, thereby calling for improvement and invention of mechanical contrivances, to assist in transporting and elevating them to the position they were to occupy; for the same reason the hardest and most costly materials were chosen, calling for further improvement in the metal forming the tools required to work them. The working of metals was further perfected in making images of the gods, and in adorning with the more precious and ornamental sorts the interior and even external parts of their shrines.

The earliest buildings of stone to which we can assign a date with any approach to accuracy, are the pyramids of Gizeh. To their builders they were sacred buildings, even more sacred than their temples or temple palaces. They were built to preserve the royal remains, until, after a lapse of 3,000 years, which we have reason to believe was the period assigned, the spirit which had once animated the body should re-enter it. Although built 5,000 years ago, the masonry of the Pyramids could not be surpassed in these days; all those who have seen and examined them, as I myself have done, agree in this; moreover, the design is perfect for the purpose for which they were intended, above all to endure. This building of pyramids in Egypt continued for some ten centuries, and from 60 to 70 still remain, but none are so admirably constructed as those of Gizeh. Still, many contain enormous blocks of granite from 30 to 40 feet long, weighing more than 300 tons, and display the greatest ingenuity in the way in which the sepulchral chambers are constructed and concealed.

The genius for dealing with large masses in building did not pass away with the pyramid builders in Egypt, but their descendants continued to gain in mechanical knowledge, judging from the enormous blocks which they handled with precision. When the command of human labor was unlimited, the mere transport of such blocks as the statue of Rameses the Great, for instance, which weighed over 800 tons, need not so greatly excite our wonder; and we know how such blocks were moved from place to place, for it is shown on the wall paintings of tombs of the period which still remain.

But as the weight of the mass to be moved is increased, it becomes no longer a question of only providing force in the shape of human bone and muscle. In moving in the last century the block which now forms the base for the statue of Peter the Great, at St. Petersburg, and which weighs 1,200 tons, force could be applied as much as was wanted, but great difficulty was experienced in supporting it, and the iron balls on which it was proposed to roll the block along were crushed, and a harder metal had to be substituted. To facilitate the transport of material, the Egyptians made solid causeways of granite from the Nile to the Pyramids; and in the opinion of Herodotus, who saw them, the causeways were more wonderful works than the Pyramids themselves.

The Egyptians have left no record of how they accomplished a far more difficult operation than the mere transport of weight—that is, how they erected obelisks weighing more than 400 tons. Some of these obelisks must have been

lifted vertically to place them in position, as they were by Fontana in Rome in later times, when the knowledge of mechanics, we know, was far advanced.

The practice of using large blocks of stone either as monoliths or as forming parts of structures has existed from the earliest times in all parts of the world.

The Peruvians used blocks weighing from 15 to 20 tons, and fitted them with the greatest nicety in their cleverly designed fortifications.

In India large blocks were used in bridges when the repugnance of Indian builders to the use of the arch rendered them necessary, or in temples, where, as in the Temple of the Sun at Orissa, stones weighing from 20 to 30 tons form part of the pyramidal roof at a height of from 70 to 80 feet from the ground. Even as late as the last century, Indians, without the aid of machinery, were using blocks of granite above 40 feet long for the doorposts of the gateway of Seringham, and roofing blocks of the same stone for a span of 21 feet.

At Persepolis, in the striking remains of the palaces of Xerxes and Darius, more than one traveler has noted the great size of the stones, some of which are stated to be 55 feet long and 6 to 10 feet broad.

So in the Greek temples of Sicily, many of the blocks in the upper parts of the temples are from 10 to 20 tons weight.

The Romans, though they did not commonly use such large stones in their own constructions, carried off the largest obelisks from Egypt and erected them at Rome, where more are now to be found than remain in Egypt. In the temples of Baalbek, erected under Roman rule, perhaps the largest stones are to be found which have been used for building since the time of the Pharaohs. The terrace wall of one of the temples is composed of three courses of stones, none of which are less than 30 feet long ; and one stone still lies in the quarry squared and ready for transport, which is 70 feet long and 14 feet square, and weighs upwards of 1,135 tons, or nearly as much as one of the tubes of the Britannia Bridge.

I have not mentioned dolmens and menhirs, rude unhewn stones often weighing from 30 or 40 tons, which are found from Ireland to India, and from Scandinavia to the Atlas, in Africa. To transport and erect such rude masses required little mechanical knowledge or skill, and the operation has excited more wonder than it deserves. Moreover, Fergusson has gone far to show that the date assigned to many of them hitherto has been far too remote ; most, and possibly all, of those in northern and western Europe having been erected since the time of the Roman occupation. And to this day the same author shows that menhirs, single stones often weighing over 20 tons, are erected by hill tribes of India in close proximity to stone buildings of elaborate design and finished execution, erected by another race of men.

For whatever purpose these vast stones were selected—whether to enhance the value or to prolong the endurance of the buildings of which they formed a part—the tax on the ingenuity of those who moved and placed them must have tended to advance the knowledge of mechanical appliances.

The ancient Assyrians and Egyptians had possibly more knowledge of mechanical appliances than they are generally credited with. In the wall paintings and sculptures which show their mode of transporting large blocks of stone, the lever is the only mechanical power represented, and which they appear to have used in such operations ; nor ought we to expect to find any other used, for, where the supply of human labor was unlimited, the most expeditious mode of dragging a heavy weight along would be by human power ; to have applied pulleys and capstans, such as would now be employed in similar undertakings, would have been mere waste of time. In some countries, even now, where manual labor is more plentiful than mechanical appliances, large numbers of men are employed to transport heavy weights, and do the work in less time than it could be done with all our modern mechanical appliances. In other operations, such as raising obelisks, or the large stones used in their temple palaces, where human labor could not be applied to such advantage, it is quite possible that the Egyptians used mechanical aids. On one of the carved slabs which formed part of the wall panelling of the

palace of Sardanapalus, which was built about 930 years before our era, a single pulley is clearly shown, by which a man is in the act of raising a bucket—probably drawing water from a well.

It has sometimes been questioned whether the Egyptians had a knowledge of steel. It seems unreasonable to deny them this knowledge. Iron was known at the earliest times of which we have any record. It is often mentioned in the Bible, and in Homer; it is shown in the early paintings on the walls of the tombs at Thebes, where butchers are represented as sharpening their knives on pieces of metal colored blue, which were most probably pieces of steel. Iron has been found in quantity in the ruined palaces of Assyria; and in the inscriptions of that country fetters are spoken of as having been made of iron, which is also so mentioned in connection with other metals as to lead to the supposition that it was regarded as a base and common metal. Moreover, in the Great Pyramid a piece of iron was found in a place were it must have lain for 5,000 years. The tendency of iron to oxydize must render its preservation for any long period rare and exceptional. The quality of iron which is now made by the native races of Africa and India is that which is known as wrought iron; in ancient times, Dr. Percy says the iron which was made was always wrought iron. It is very nearly pure iron, and a very small addition of carbon would convert it into steel. Dr. Percy says the extraction of good malleable iron directly from the ore "requires a degree of skill very far inferior to that which is implied in the manufacture of bronze." And there is no great secret in making steel; the natives of India now make excellent steel in the most primitive way, which they have practised from time immemorial. When steel is to be made, the proportion of charcoal used with a given quantity of ore is somewhat larger, and the blast is applied more slowly than when wrought iron is the metal required. Thus, a vigorous native working the bellows of skin would make wrought iron where a lazy one would have made steel. The only apparatus required for the manufacture of the finest steel from iron ore is some clay for making a small furnace four feet high, and from one to two broad, some charcoal for fuel, and a skin with a bamboo tuyere for creating the blast.

The supply of iron in India as early as the fourth and fifth centuries seems to have been unlimited. The iron pillar of Delhi is a remarkable work for such an early period. It is a single piece of wrought iron 50 feet in length, and it weighs not less than 17 tons. How the Indians forged this large mass of iron and other heavy pieces which their distrust of the arch led them to use in the construction of roofs, we do not know. In the temples of Orissa iron was used in large masses as beams or girders in roof-work in the thirteenth century.

The influence of the discovery of iron on the progress of art and science cannot be over-estimated. India well repaid any advantage which she may have derived from the early civilized communities of the West if she were the first to supply them with iron and steel.

An interesting social problem is afforded by a comparison of the relative conditions of India and this country at the present time. India, from thirty to forty centuries ago, was skilled in the manufacture of iron and cotton goods, which manufacturers, is less than a century, have done so much for this country. It is true that in India coal is not so abundant or so universally distributed as in this country. Yet, if we look still further to the East, China had probably knowledge of the use of metals as soon as India, and moreover had a boundless store of iron and coal. Baron Richthofen, who has visited and described some of the coal-fields of China, believes that one province alone, that of Southern Shanshi, could supply the world at its present rate of consumption for several thousand years. The coal is near the surface, and iron abounds with it. Marco Polo tells us that coal was universally used as fuel in the parts of China which he visited towards the end of the fourteenth century, and from other sources we have reason to believe it was used there as fuel 2,000 years ago. But what progress has China made in the last ten centuries? A great future is undoubtedly in store for that country; but can the race who now dwell there develop its resources, or must they await the aid of an Aryan

race? Or is anything more necessary than a change of institutions, which might come unexpectedly, as in Japan?

The art of extracting metals from the ore was practised at a very early date in this country. The existence long ago of tin mines in Cornwall, which are so often spoken of by classical writers, is well known to all. That iron was also extracted from the ore by the ancient Britons is most probable, as it was largely used for many purposes by them before the Roman conquest. The Romans worked iron extensively in the Weald of Kent, as we assume from the large heaps of slag containing Roman coins which still remain there. The Romans always availed themselves of the mineral wealth of the countries which they conquered, and their mining operations were often carried out on the largest scale, as in Spain, for instance, where as many as forty thousand miners were regularly employed in the mines at New Carthage.

Coal, which was used for ordinary purposes in England as early as the ninth century, does not appear to have been largely used for iron smelting until the eighteenth century, though a patent was granted for smelting iron with coal in the year 1611. The use of charcoal for that purpose was not given up until the beginning of this century, since which period an enormous increase in the mining and metallurgical industries has taken place; the quantity of coal raised in the United Kingdom in 1873 having amounted to 127 million tons, and the quantity of pig iron to upwards of 6½ million tons.

The early building energy of the world was chiefly spent on the erection of tombs, temples, and palaces.

While, in Egypt, as we have seen, the art of building in stone had 5,000 years ago reached the greatest perfection, so in Mesopotamia the art of building with brick, the only available material in that country, was in an equally advanced state some ten centuries later. That buildings of such a material have lasted to this day shows how well the work was done; their ruinous condition even now is owing to their having served as quarries for the last three or four thousand years, so that the name of Nebuchadnezzar, apparently one of the greatest builders of ancient times, is as common on the bricks of many modern towns in Persia as it was in old times in Babylon. The labor required to construct the brick temples and palaces of Chaldæa and Assyria must have been enormous. The mound of Koyunjik alone contained 14½ million tons, and represents the labor of 10,000 men for twelve years. The palace of Sennacherib, which stood on this mound, was probably the largest ever built by any one monarch, containing as it did more than two miles of walls, panelled with sculptured alabaster slabs, and twenty-seven portals, formed by colossal bulls and sphinxes.

The pyramidal temples of Chaldæa are not less remarkable for the labor bestowed on them, and far surpass the buildings of Assyria in the excellence of their brickwork.

The practice of building great pyramidal temples seems to have passed eastwards to India and Burmah, where it appears in buildings of a later date, in Buddhist topes and pagodas; marvels of skill in masonry, and far surpassing the old brick mounds of Chaldæa in richness of design and in workmanship. Even so late as this century a king of Burmah began to build a brick temple of the old type, the largest building, according to Fergusson, which has been attempted since the Pyramids.

The mere magnitude of many of these works is not so wonderful when we take into account the abundance of labor which those rulers could command. Countries were depopulated, and their inhabitants carried off and made to labor for the conquerors. The inscriptions of Assyria describe minutely the spoils of war and the number of captives; and in Egypt we have frequent mention made of works being executed by the labor of captive peoples. Herodotus tells us that as many as 360,000 men were employed in building one palace for Sennacherib. At the same time it must not be forgotten that the very character of the multitude would demand from some one the skill and brain to organize and direct, to design and plan the work.

It would be surprising if men who were capable of undertaking and successfully completing unproductive works of such magnitude did not also employ

their powers on works of a more useful class. Traces still remain of such works; enough to show, when compared with the scanty records of the times which have come down to us, that the prosperity of such countries as Egypt and Mesopotamia was not wholly dependant on war and conquest, but that the reverse was more likely the case, and that the natural capabilities of those countries were greatly enlarged by the construction of useful works of such magnitude as to equal, if not in some cases surpass, those of modern times.

Egypt was probably far better irrigated in the days of the Pharaohs than it is now. To those unacquainted with the difficulties which must be met with and overcome before a successful system of irrigation can be carried out, even in countries in which the physical conditions are favorable, it may appear that nothing more is required than an adequate supply of unskilled labor. Far more than this was required: the Egyptians had some knowledge of surveying, for Eustathius says they recorded their marches on maps; but such knowledge was probably in those days very limited, and it required no ordinary grasp of mind to see the utility of such extensive works as were carried out in Egypt and Mesopotamia, and, having seen the utility, to successfully design and execute them. To cite one in Egypt—Lake Mœris, of which the remains have been explored by M. Linant, was a reservoir made by one of the Pharaohs, and supplied by the flood waters of the Nile. It was 150 square miles in extent, and was retained by a bank or dam 60 yards wide and 10 high, which can be traced for a distance of thirteen miles. This reservoir was capable of irrigating 1,200 square miles of country. No work of this class has been undertaken on so vast a scale since, even in these days of great works.

The prosperity of Egypt was in so great a measure dependent on its great river, that we should expect that the Egyptians, a people so advanced in art and science, would at an early period have made themselves acquainted with its *régime*. We know that they carefully registered the height of the annual rise of its waters; such registers still remain inscribed on the rocks on the banks of the Nile, with the name of the king in whose reign they were made. The people of Mesopotamia were equally observant of the *régime* of their great rivers, and took advantage in designing their canals of the different periods in the rising of the waters of the Tigris and Euphrates. A special officer was appointed in Babylon, whose duty it was to measure the rise of the river; and he is mentioned in an inscription found in the ruins of that city, as recording the height of the water in the Temple of Bel. The Assyrians, who had a far more difficult country to deal with, owing to its rocky and uneven surface, showed even greater skill than the Babylonians in forming their can ls, tunneling through rock, and building dams of masonry across the Euphrates. While the greater number of these canals in Egypt and Mesopotamia were made for the purpose of irrigation, others seem to have been made to serve at the same time for navigation. Such was the canal which effected a junction between the Mediterranean and the Red Sea, which was a remarkable work, having regard to the requirements of the age in which it was made. Its length was about eighty miles; its width admitted of two triremes passing one another. At least one of the navigable canals of Babylonia, attributed to Nebuchadnezzar, can compare in extent with any work of later times. I believe Sir H. Rawlinson has traced the canal to which I allude throughout the greater part of its course, from Hit on the Euphrates to the Persian Gulf, a distance of between four and five hundred miles. It is a proof of the estimation in which such works were held in Babylonia and Assyria, that, among the titles of the god Vul were those of "Lord of Canals," and "The Establisher of Irrigation Works."

The springs of knowledge which had flowed so long in Babylonia and Assyria were dried up at an early period. With the fall of Babylon and destruction of Nineveh the settled population of the fertile plains around them disappeared, and that which was desert before man led the waters over it became desert again, affording a wide field for, and one well worthy of, the labors of engineers to come.

Such was not the case with Egypt.

Long after the period of its greatest prosperity was reached, it remained the fountain head from whence knowledge flowed to Greece and Rome. The Philosophers of Greek and those who, like Archimedes, were possessed of the best mechanical knowledge of the time, repaired to Egypt to study and obtain the foundation of their knowledge from thence.

Much as Greece and Rome were indebted to Egypt, it will probably be found, as the inscribed tablets met with in the mounds of Assyria and Chaldæa are deciphered, that the latter civilizations owe, if not more, at least as much, to those countries as to Egypt. This is the opinion of Mr. Smith, who, in his work describing his recent interesting discoveries in the East, says that the classical nations "borrowed far more from the valley of the Euphrates than that of the Nile."

In the science of astronomy, which in these days is making such marvellous discoveries, Chaldæa was undoubtedly preeminent. Among the many relics of these ancient peoples which Mr. Smith has recently brought to this country is a portion of a metal astrolabe from the palace of Sennacherib, and a tablet on which is recorded the division of the heavens according to the four seasons, and the rule for regulating the intercalary month of the year. Not only did the Chaldæans map out the heavens and arrange the stars, but they traced the motion of the planets, and observed the appearance of comets; they fixed the signs of the zodiac, and they studied the sun and moon and the periods of eclipses.

But to return to that branch of knowledge to which I wish more particularly to draw your attention, as it grew and spread from east to west, from Asia over Europe. Of all nations of Europe the Greeks were most intimately connected with the civilization of the East. A maritime people by the nature of the land they lived in, colonization followed as a matter of course on the tracks of their trading vessels; and thus, more than any other people, they helped to spread Eastern knowledge along the shores of the Mediterranean, and throughout the shores of Europe.

The early constructive works of Greece, till about the seventh century B. C., form a strong contrast to those of its more prosperous days. Commonly called Pelasgian, they are more remarkable as engineering works than admirable as those which followed them were for architectural beauty. Walls of huge unshapely stones—admirably fitted together, however—tunnels and bridges characterize this period. In Greece, during the few and glorious centuries which followed, the one aim in all construction was to please the eye, to gratify the sense of beauty; and in no age was that aim more thoroughly and satisfactorily attained.

In these days, when sanitary questions attract each year more attention, we may call to mind that twenty-three centuries ago the city of Agrigentum possessed a system of sewers, which, on account of their large size, were thought worthy of mention by Diodorus. This is not, however, the first record of towns being drained; the well known Cloaca Maxima, which formed part of the drainage system of Rome, was built some two centuries earlier, and great vaulted drains passed beneath the palace mounds of unburnt brick at Nimrod and Babylon; and possibly we owe the preservation of many of the interesting remains found in the brick mounds of Chaldæa to the very elaborate system of pipe drainage discovered in them, and described by Loftus.

Whilst Pelasgian art was being superseded in Greece, the city of Rome was founded in the eighth century before our era; and Etruscan art in Italy, like the Pelasgian art in Greece, was slowly merged in that of an Aryan race. The Etruscans, like the Pelasgians and the old Egyptians, were Turanians, and remarkable for their purely constructive or engineering works. Their city walls far surpass those of any other ancient race, and their drainage works and tunnels are most remarkable.

The only age which can compare with the present one in the rapid extension of utilitarian works over the face of the civilized world, is that during which the Romans, an Aryan race, as we are, were in power. As Fergusson has said, the mission of the Aryan races appears to be to pervade the world with useful and industrial arts. That the Romans adorn-

ed their bridges, their aqueducts, and their roads; that with a sound knowledge of construction they frequently made it subservient to decoration, was partly owing to the mixture of Etruscan or Turanian blood in their veins, and partly to their great wealth, which made them disregard cost in their construction, and to their love of display.

It would be impossible for me to do justice to even a small part of the engineering works which have survived fourteen centuries of strife, and remain to this day as monuments of the skill, the energy, and ability of the great Roman people. Fortunately, their works are more accessible than those of which I have spoken hitherto, and many of you are probably already familiar with them.

Conquerors of the greater part of the civilized world, the admirable organization of the Romans enabled them to make good use of the unbounded resources which were at their disposal. Yet, while the capital was enriched, the development of the resources of the most distant provinces of the empire was never neglected.

War, with all its attendant evils, has often indirectly benefited mankind. In the long sieges which took place during the old wars of Greece and Rome, the inventive power of man was taxed to the utmost to provide machines for attack and defence. The ablest mathematicians and philosophers were pressed into the service, and helped to turn the scale in favor of their employers. The world has to regret the loss of more than one, who, like Archimedes, fell slain by the soldiery while applying the best scientific knowledge of the day to devising means of defence during the siege. In these days, too, science owes much to the labors of engineers and able men, whose time is spent in making and improving guns, the materials composing them, and armor plates to resist them, or in studying the motion of ships of war in a seaway.

The necessity for roads and bridges for military purposes has led to their being made where the necessary stimulus from other causes was wanting; and so means of communication, and the interchange of commodities, so essential to the prosperity of any community, have thus been provided. Such was the case under the Roman Empire. So, too, in later times the ambition of Napoleon covered France and the countries subject to her with an admirable system of military roads. At the same time, we must do Napoleon the justice of saying that his genius and foresight gave a great impetus to the construction of all works favorable to commercial progress. So, again, in this country it was the rebellion of 1745, and the want felt of roads for military purposes, which first led to the construction of a system of roads in it unequaled since the time of the Roman occupation. And lastly, in India, in Germany, and in Russia, more than one example could be pointed out where industry will benefit by railways which have originated in military precautions rather than in commercial requirements.

But to return to Rome. Roads followed the tracks of her legions into the most distant provinces of the empire. Three hundred and seventy-two great roads are enumerated, together more than 48,000 miles in length, according to the itinerary of Antoninus.

The water supply of Rome during the first century of our era would suffice for a population of seven millions, supplied at the rate at which the present population of London is supplied. This water was conveyed to Rome by nine aqueducts; and in later years the supply was increased by the construction of five more aqueducts. Three of the old aqueducts have sufficed to supply the wants of the city in modern times. These aqueducts of Rome are to be numbered among her grandest engineering works. Time will not admit of my saying anything about her harbor works and bridges, her basilicas and baths, and numerous other works in Europe, in Asia, and in Africa. Not only were these works executed in a substantial and perfect manner, but they were maintained by an efficient staff of men divided into bodies, each having their special duties to perform. The highest officers of state superintended the construction of works, were proud to have their names associated with them, and constructed extensive works at their own expense.

Progress in Europe stopped with the fall of the Roman Empire. In the

fourth and succeeding centuries the barbarian hordes of Western Asia, people who felt no want of roads and bridges, swept over Europe to plunder and destroy.

With the seventh century began the rise of the Mohammedan power, and a partial return to conditions apparently more favorable to the progress of industrial art, when widespread lands were again united under the sway of powerful rulers. Science owes much to Arab scholars, who kept and handed on to us the knowledge acquired so slowly in ancient times, and much of which would have been lost but for them. Still, few useful works remain to mark the supremacy of the Mohammedan power at all comparable to those of the age which preceded its rise.

A great building age began in Europe in the tenth century, and lasted through the thirteenth. It was during this period that these great ecclesiatical buildings were erected, which are not more remarkable for artistic excellence than for boldness in design.

While the building of cathedrals progressed on all sides in Europe, works of utilitarian character, which concern the engineer, did not receive such encouragement, excepting perhaps in Italy.

From the twelfth to the thirteenth centuries, with the revival of the arts and sciences in the Italian republics, many important works were undertaken for the improvement of the rivers and harbors of Italy. In 1481 canal locks were first used ; and some of the earliest of which we have record were erected by Leonardo da Vinci, who would be remembered as a skillful engineer had he not left other greater and more attractive works to claim the homage of posterity.

The great use that has since been made of this simple means of transferring floating vessels from one water level to another, in connection not only with inland navigation, but in all the great ports and harbors of the world, renders it all the more deserving of remark.

In India, under the Moguls, irrigation works, for which they had a natural aptitude, were carried on during these centuries with vigor, and more than one emperor is noted for the numerous great works of this nature which he carried out. If the native records can be trusted, the number of hydraulic works undertaken by some rulers is surprising. Tradition relates that one king who reigned in Orissa in the twelfth century made one million tanks or reservoirs, besides building sixty temples, and erecting numerous other works.

In India, the frequent overflow of the great rivers, and the periodical droughts, which rendered irrigation necessary, led to extensive protective works being undertaken at an early period ; but as these works have been maintained by successive rulers, Mogul and Mohammedan, until recent times, and have not been left for our inspection, deserted and useless for 3,000 years or more, as is often the case in Egypt and Mesopotamia, there is more difficulty in ascertaining the date of such works in India.

Works of irrigation were among the earliest attempts at engineering undertaken by the least civilized inhabitants in all parts of the world. Even in Australia, where savages are found as low as any in the scale of civilization, traces of irrigation works have been found ; these works, however, must be taken to show that the natives were once somewhat more civilized than we now find them. In Feejee, our new possession, the natives occasionally irrigate their land, and have executed a work of a higher class, a canal some two miles long and sixty feet wide, to shorten the distance passed over by their conoes. The natives of New Caledonia irrigate their fields with great skill. In Peru, the Incas excelled in irrigation as in other great and useful works, and constructed most admirable underground conduits of masonry for the purpose of increasing the fertility of the land.

It is frequently easier to lead water where it is wanted than to check its irruption into places where its presence is an evil, often a disaster. For centuries the existence of a large part of Holland has been dependent on the skill of man. How soon he began in that country to contest with the sea the possession of the land we do not know, but early in the twelfth century dykes were constructed to keep back the ocean. As the prosperity of the country increased with the great extension of its

commerce, and land became more valuable and necessary for an increasing population, very extensive works were undertaken. Land was reclaimed from the sea, canals were cut, and machines were designed for lifting water. To the practical knowledge acquired by the Dutch, whose method of carrying out hydraulic works is original and of native growth, much of the knowledge of the present day in embanking, and draining, and canal making is due. The North Holland Canal was the largest navigable canal in existence until the Suez Canal was completed; and the Dutch have just now nearly finished making a sea canal from Amsterdam to the North Sea, which, though not equal to the Suez Canal in length, will be as great in width and depth, and involves perhaps larger and more important works of art. This country was for many years beholden to the Dutch for help in carrying out hydraulic works. In the seventeenth century much fen land in the eastern counties was drained by Dutch labor, directed by Dutch engineers, among whom Sir Cornelius Vermuyden, an old campaigner of the Thirty Years' War and a colonel of horse under Cromwell, is the most noted.

While the Dutch were acquiring practical knowledge in dealing with water, and we in Britain among others were benefiting by their experience, the disastrous results which ensued from the inundations caused by the Italian rivers of the Alps gave a new importance to the science of hydraulics. Some of the greatest philosophers of the seventeenth century—among them Torricelli, a pupil of Galileo,—were called upon to advise and to superintend engineering works; nor did they confine themselves to the construction of preventive works, but thoroughly investigated the condition pertaining to fluids at rest or in motion, and gave to the world a valuable series of works on hydraulics and hydraulic engineering, which form the basis of our knowledge of these subjects at the present day.

Some of the best scientific works (prior to the nineteenth century) on engineering subjects we owe to Italian and French writers. The writings of Belidor, an officer of artillery in France in the seventeenth century, who did not, however, confine himself to military subjects, drew attention to engineering questions. Not long after their appearance, the Ponts et Chausees were established, which has maintained ever since a body of able men specially educated for, and devoted to, the prosecution of industrial works.

The impulse given to road-making in the early part of the last century soon extended to canals and means for facilitating locomotion and transport generally. Tramways were used in connection with mines at least as early as the middle of the seventeenth century, but the rails were, in those days, of wood. The first iron rails are said to have been laid in this country as early as 1738; after which time their use was gradually extended, until it became general in mining districts.

By the beginning of this century the great ports of England were connected by a system of canals; and new harbor works became necessary, and were provided to accommodate the increase of commerce and trade, which improved means of internal transport had rendered possible. It was in the construction of these works that our own Brindley and Smeaton, Telford and Rennie, and other engineers of their time, did so much.

But it was not untill the steam-engine, improved and almost created by the illustrious Watt, became such a potent instrument, that engineering works to the extent they have since been carried out became possible or necessary. It gave mankind no new faculty, but it at once set his other faculties on an eminence, from which the extent of his future operations became almost unlimited.

Water-mills, wind-mills, and horse-machines were in most cases superseded. Deep mines, before only accessible by adits and water levels, could at once be reached with ease and economy. Lakes and fens which, but for the steam-engine, would have been left untouched, were drained and cultivated.

The slow and laborious toil of hands and fingers, bone and sinew, was turned to other employments, where, aided by ingenious mechanical contrivances, the produce of one pair of hands was multiplied a thousand-fold, and their cunning

extended until results marvelous, if you consider them, were attained. Since the time of Watt the steam-engine has exerted a power, made conquests, and increased and multiplied the material interests of this globe to an extent which it is scarcely possible to realize.

But while Watt has gained a world-wide, well-earned fame, the names of those men who have provided the machines to utilize the energies of the steam-engines are too often forgotten. Of their inventions the majority of mankind know little. They worked silently at home, in the mill, or in the factory, observed by few. Indeed, in most cases these silent workers had no wish to expose their work to public gaze. Were it not so, the factory and the mill are not places where people go to take the air. How long in the silent night the inventors of these machines sat and pondered; how often they had to cast aside some long-sought mechanical movement and seek another and a better arrangement of parts, none but themselves could ever know. They were unseen workers, who succeeded by rare genius, long patience, and indomitable perseverance.

More ingenuity and creative mechanical genius is perhaps displayed in machines used for the manufacture of textile fabrics than by those used in any other industry. It was not until late in historical times that the manufacture of such fabrics became established on a large scale in Europe. Although in China man was clothed in silk long ago, and although Confucius, in a work written 2,300 years ago, orders with the greatest minuteness the rules to be observed in the production and manufacture of silk, yet it was worth nearly its weight in gold in Europe in the time of Aurelian, whose empress had to forego the luxury of a silk gown on account of its cost? Through Constantinople and Italy the manufacture passed slowly westwards, and was not established in France until the sixteenth century, and arrived at a still later period in this country. It is related that James V. had to borrow a pair of silk hose from the Earl of Mar, in order that he might not, as he expressed it, appear as a scrub before strangers.

So cotton, of which the manufacture in India dates from before historical times, had scarcely by the Christian era reached Persia and Egypt. Spain in the tenth and Italy in the fourteenth century manufactured it, but Manchester, which is now the great metropolis of the trade, not until the latter half of the seventeenth century.

Linen was worn by the old Egyptians, and some of their linen mummy cloths surpass in fineness any linen fabrics made in later days. The Babylonians wore linen also and wool, and obtained a wide-spread fame for skill in workmanship and beauty in design.

In this country wool once formed the staple for clothing. Silk was the first rival, but its costliness placed it beyond the reach of the many. To introduce a new material or improved machine into this or other countries a century or more ago was no light undertaking. Inventors and would-be benefactors alike, ran the risk of loss of live. Loud was the outcry made in the early part of the eighteenth century against the introduction of Indian cottons and Dutch calicoes.

Until 1738, in which year the improvements in spinning machinery were begun, each thread of worsted or cotton wool had been spun between the fingers in this and all other countries. Wyatt, in 1738, invented spinning by rollers instead of fingers, and his invention was further improved by Arkwright. In 1770 Hargreaves patented the spinning jenny, and Crompton the mule in 1775, a machine which combined the advantages of the frames of both Hargreaves and Arkwright. In less than a century after the first invention by Wyatt, double mules were working in Manchester with over 2,000 spindles. Improvements in machines for weaving were begun at an earlier date. In 1579 a ribbon loom is said to have been invented at Dantzic, by which from four to six pieces could be woven at one time, but the machine was destroyed and the inventor lost his life. In 1800 Jacquard's most ingenious invention was brought into use, which, by a simple mechanical operation, determines the movements of the threads which form the pattern in weaving. But the greatest discovery in the art of weaving was wrought by Cartwright's discovery of the power loom, which led eventually to the sub-

stitution of steam for manual labor, and enabled a boy with a steam loom to do fifteen times the work of a man with a hand loom.

Steamboats, the electric telegraph, and railways, are more within the cognizance of the world at large, and the progress that has been made in them in little more than one generation is better known and appreciated.

It is not more than forty years since one of our scientific men, and an able one too, declared at a meeting of this Association that no steamboat would ever cross the Atlantic; founding his statement on the impracticability, in his view, of a steamboat carrying sufficient coal, profitably, I presume, for the voyage. Yet, soon after this statement was made, the *Sirius* steamed from Bristol to New York in seventeen days, and was soon followed by the *Great Western*, which made the homeward passage in thirteen-and-a-half days; and with these voyages the era of steamboats began. Like most important inventions, that of the steamboat was a long time in assuming a form capable of being profitably utilized; and even when it had assumed such a form, the objections of commercial and scientific men had still to be overcome.

The increase in the number of steamboats since the time when the *Sirius* first crossed the Atlantic has been very great. Whereas in 1814 the United Kingdom only possessed two steam vessels, of together 456 tons burden, in 1872 there were on the register of the United Kingdom 3,662 steam vessels, of which the registered tonnage amounted to over a million and a half of tons, or to nearly half the whole steam tonnage of the world, which did not at that time greatly exceed three million tons.

As the number of steamboats has largely increased, so also gradually has their size increased until it culminated in the hands of Brunel in the *Great Eastern*.

A triumph of engineering skill in shipbuilding, the *Great Eastern* has not been commercially so successful. In this, as in many other engineering problems, the question is not how large a thing can be made, but how large, having regard to other circumstances, it is proper at the time to make it.

If, as regards the dimensions of steamboats, we have at present somewhat overstepped the limits in the *Great Eastern*, much still remains to be done in perfecting the form of vessels, whether propelled by steam or driven by the force of the wind. A distinguished member of this Association, Mr. Froude, has now for some years devoted himself to investigations carried on with a view to ascertain the form of vessel which will offer the least resistance to the water through which it must pass. So many of us in these days are called upon to make journeys by sea as well as by land, that we can well appreciate the value of Mr. Froude's labors, so far as they tend to curtail the time which we must spend on our ocean journeys; and we should all feel grateful to him if from another branch of his investigations, which relates to the rolling of ships, it should result that the movement in passenger vessels could be reduced.

As improvements in the form of the hull are effected, less power—that is, less fuel—will be required to propel the vessel through the water for a given distance. Great as have been the improvements effected in marine engines to this end, much still remains to be done. Wolf's compound engine, so long overlooked, is, with some improvements, being at last applied. Whereas the consumption of fuel in such vessels as the *Himalaya* used to be from 5 to 6 lbs. of fuel per effective horse-power, it has been reduced, by working steam more expansively in vessels of a later date, to 2 lbs. Yet, comparing this with the total amount of energy of 2 lbs. of coal, it will be found that not a tenth part of the power is obtained which that amount of coal would theoretically call into action.

There is no more remarkable instance of the rapid utilization of what was in the first instance regarded by most men as a mere scientific idea, than the adoption and extension of the electric telegraph.

Those who read Odier's letter written in 1773, in which he made known his idea of a telegraph which would enable the inhabitants of Europe to converse with the Emperor of Mogul, little thought that in less than a century a

conversation between persons at points so far distant would be possible. Still less did those who saw in the following year messages sent from one room to another by Lesage in the presence of Friedrich of Prussia, realize that they had before them the germ of one of the most extraordinary inventions among the many that will render this century famous.

I should weary you were I to follow the slow steps by which the electric telegraph of to-day was brought to its present state of efficiency. In the present century few years have passed without new workers appearing in the field; some whose object was to utilize the new-found power for the benefit of mankind, others—and their work was not the least important in the end—whose object was to investigate magnetism and electrical phenomena as presenting scientific problems still unsolved. Galvani, Volta, Oersted, Arago, Sturgeon, and Faraday, by their labors, helped to made known the elements which rendered it possible to construct the electric telegraph. With the battery, the electric coil, and the electro-magnet, the elements were complete, and it only remained for Sir Charles Wheatstone and others to combine them in a useful and practically valuable form. The inventions of Alexander, Steinheil, and those of similar nature to that of Sir Charles Wheatstone, were made known at a later date in the same year, which will ever be memorable in the annals of telegraphy.

The first useful telegraph was constructed upon the Blackwall Railway in 1838, Messrs. Wheatstone's and Cooke's instruments being employed. From that time to this the progress of the electric telegraph has been so rapid, that at the present time, including land lines and submarine cables, there are in use in different parts of the world not less than 400,000 miles of telegraph.

Among the numerous inventions of late years, the outomatic telegraph of Mr. Alexander Bain, of Dr. Werner Siemens, and of Sir Charles Wheatstone, are especially worthy of notice. Mr. Bain's machine is cheifly used in the United States, that of Dr. Werner Siemens in Germany. In this country the machine invented by Sir Charles Wheatstone, to whom telegraphy owes so much, is chiefly employed. By his machine, after the message has been punched out in a paper ribbon by one machine on a system analogous to the dot and dash of Morse, the sequence of the currents requisite to transmit the message along the wire is automatically determined in a second machine by this perforated ribbon. This second operation is analogous to that by which in Jacquard's loom the motions of the threads requisite to produce the pattern is determined by perforated cards. By Wheatstone's machine errors inseparable from manual labor are avoided; and what is of even more importance in a commercial point of view, the time during which the wire is occupied in the transmission of a message is considerably diminished.

By the application of these automatic systems to telegraphy, the speed of transmission has been wonderfully accelerated, being equal to 200 words a minute, that is, faster than a shorthand writer can transcribe; and, in fact, words can now be passed along the wires of land lines with a velocity greater than can be dealt with by the human agency at either end.

Owing partly to the retarding effects of induction and other causes, the speed of transmission by long submarine cables is much smaller. With the cable of 1858 only 2½ words per minute were got through. The average with the Atlantic cable, Dr. C. W. Siemens informs me, is now seventeen words, but twenty-four words per minute can be read.

One of the most striking phenomena in telegraphy is that known as the duplex system, which enables messages to be sent from each end of the same wire at the same time. This simultaneous transmission from both ends of a wire was proposed in the early days of telegraphy, but, owing to imperfect insulation, was not then found to be practicable; but since then telegraphic wires have been better insulated, and the system is now becoming of great utility, as it nearly doubles the capacity for work of every wire.

Of railways the progress has been enormous, but I do not know that in a scientific point of view a railway is so marvelous in its character as the electric telegraph. The results, however,

of the construction and use of railways are more extensive and widespread, and their utility and convenience brought home to a larger portion of mankind. It has come to pass, therefore, that the name of George Stephenson has been placed second only to that of James Watt; and as men are and will be estimated by the advantages which their labors confer on mankind, he will remain in that niche, unless indeed some greater luminary should arise to outshine him. The merit of George Stephenson consisted, among other things, in this, that he saw more clearly than any other engineer of his time the sort of thing that the world wanted, and that he persevered in despite of learned objectors with the firm conviction that he was right and they were wrong, and that there was within himself the power to demonstrate the accuracy of his convictions.

We who live in these days of roads and railways, and can move with a fair degree of comfort, speed, and safety, almost where we will, can scarcely realize the state of England two centuries ago, when the years of opposition which preceded the era of coaches began; when, as in 1662, there were but six stages in all England, and John Crossdell, of the Charterhouse, thought there were six too many; when Sir Henry Herbert, a member of the House of Commons, could say, "If a man were to propose to carry us regularly to Edinburgh in coaches in seven days, and bring us back in seven more, should we not vote him to Bedlam?"

In spite of short-sighted opposition, coaches made their way; but it was not till a century later, in 1784,—and then I believe it was in this city of Bristol—that coaches were first established for the conveyance of mails. Those here who have experienced, as I have, what the discomforts were of long journeys inside the old coaches, will agree with me that they were very great; and I believe, if returns could be obtained of the accidents which happened to coaches, it would be found that many more people were injured and killed in proportion to the number that traveled by that mode than by the railways of to-day.

No sooner had our ancestors settled down with what comfort was possible in their coaches, well satisfied that twelve miles an hour was the maximum speed to be obtained or that was desirable, than they were told that steam conveyance on iron railways would supersede their "present pitiful" methods of conveyance. Such was the opinion of Thomas Gray, the first promoter of railways, who published his work on a general iron railway in 1819. Gray was looked on as little better than a madman.

Railways add enormously to the national wealth. More than twenty-five years ago it was proved to the satisfaction of a committee of the House of Commons, from facts and figures which I then adduced, and the Lancashire and Yorkshire Railway, of which I was the engineer, and which then formed the principal railway connection between the populous towns of Lancashire and Yorkshire, effected a saving to the public using the railway of more than the whole amount of the dividend which was received by the proprietors. These calculations were based solely on the amount of traffic carried by the railway, and on the difference between the railway rate of charge and the charges by the modes of conveyance anterior to railways. No credit whatever was taken for the saving of time, though in England preeminently time is money.

Considering that railway charges on many items have been considerably reduced since that day, it may be safely assumed that the railways in the British Islands now produce, or rather save to the nation, a much larger sum annually than the gross amount of all the dividends payable to the proprietors, without at all taking into account the benefit arising from the saving in time. The benefits under that head defy calculation, and cannot with any accuracy be put into money; but it would not be at all over-estimating this question to say that in time and money the nation gains at least what is equivalent to 10 per cent. on all the capital expended on railways. I do not urge this on the part of railway proprietors, for they did not embark in these undertakings with a view to the national gain, but for the expected profit to themselves. Yet it is as well it should be noted, for railway proprietors appear sometimes by some

people to be regarded in the light of public enemies.

It follows from these facts that whenever a railway can be made at a cost to yield the ordinary interest of money, it is in the national interest that it should be made. Further, that though its cost might be such as to leave a smaller dividend than that to its proprietors, the loss of wealth to so small a section of the community will be more than supplemented by the national gain, and therefore there may be cases where a Government may wisely contribute in some form to undertakings which, without such aid, would fail to obtain the necessary support.

Mr. Bramwell, when presiding over the Mechanical Section at Brighton, drew attention to the waste of fuel.

Dr. Siemens, in an able lecture he delivered by request of the Association to the operative classes at the meeting at Bradford, pointed out the waste of fuel in special branches of the iron trade, to which he has devoted so much attention.

He showed on that occasion that, in the ordinary re-heating furnace, the coal consumed did not produce the twentieth part of its theoretical effect, and in melting steel in pots in the ordinary way not more than one-seventieth part; in melting one ton of steel in pots about 2½ tons of coke being consumed. Dr. Siemens further stated that, in his regenerative gas furnace, one ton of steel was melted with 12 cwt. of small coal.

Mr. Lowthian Bell, who combines chemical knowledge with the practical experience of an ironmaster, in his Presidential address to the members of the Iron and Steel Institute in 1873, stated that, with the perfect mode of withdrawing and utilizing the gases and the improvement in the furnaces adopted in the Cleveland district, the present make of pig-iron in Cleveland is produced with 3½ million tons of coal less than would have been needed fifteen years ago; this being equivalent to a saving of 45 per cent. of the quantity formerly used. He shows by figures, with which he has favored me, that the calorific power of the waste gases from the furnaces is sufficient for raising all the steam and heating all the air the furnaces require.

It has already been stated that by working steam more expansively, either in double or single engines, the consumption of fuel in improved modern engines compared with the older forms may be reduced to one-third.

All these reductions still fall far short of the theoretical effect of fuel which may be never reached. Mr. Lowthian Bell's figures go to show that in the interior of the blast furnace, as improved in Cleveland, there is not much more to be done in reducing the consumption of fuel; but much has already been done, and could the reductions now attainable, and all the information already acquired be universally applied, the saving in fuel would be enormous.

If I have pointed out that we do not avail ourselves of more than a fractional part of the useful effects of fuel, it is not that I expect we shall all at once mend our ways in this respect. Many cases of waste arise from the existence of old and obsolete machines, of bad forms of furnaces, of wasteful grates, existing in most dwelling-houses; and these are not to be remedied at once, for not everyone can afford, however desirable it might be, to cast away the old and adopt the new.

In looking uneasily to the future supply and cost of fuel, it is, however, something to know what may be done even with the application of our present knowledge; and could we apply it universally to-day, all that is necessary for trade and comfort could probably be as well provided for by one-half the present consumption of fuel; and it behoves those who are beginning to build new mills, new furnaces, new steamboats, or new houses, to act as though the price of coal which obtained two years ago had been the normal and not the abnormal price.

"Whence and whither," is an aphorism which leads us away from present and plainer objects to those which are more distant and obscure; whether we look backwards or forwards, our vision is speedily arrested by an impenetrable veil.

On the subjects I have chosen you will probably think I have traveled backwards far enough. I have dealt to some extent with the present.

The retrospect, however, may by use-

ful to show what great works in former ages.

Some things have been better done than in those earlier times, but not all.

In what we choose to call the ideal we do not surpass the ancients. Poets and painters and sculptors were as great in former times as now; so, probably, were the mathematicians.

In what depends on the accumulation of experience, we ought to excel our forerunners. Engineering depends largely on experience; nevertheless, in future times, whenever difficulties shall arise or works have to be acomplished for which there is no precedent, he who has to perform the duty may step forth from any of the walks of life, as engineers have not unfrequently hitherto done.

The marvelous progress of the last two generations should make everyone cautious of predicting the future. Of engineering works, however, it may be said that their practicability or impracticability is often determined by other elements than the inherent difficulty in the works themselves. Greater works than any yet achieved remain to be accomplished—not perhaps yet awhile. Society may not yet require them; the world could not at present afford to pay for them.

The progress of engineering works, if we consider it, and the expenditure upon them, has already in our time been prodigious. One hundred and sixty thousand miles of railway alone, put into figures at 20,000*l.* a mile, amounts to 3,200 million pounds sterling; add 400,000 miles of telegraph at 100*l.* a mile, and 100 millions more for sea canals, docks, harbors, water and sanitary works constructed in the same period, and we get the enormous sum of 3,340 millions sterling expended in one generation and a half on what may undoubtedly be called useful works.

The wealth of nations may be impaired by expenditure on luxuries and war; it cannot be diminished by expenditure on works like these.

As to the future, we know we cannot create a force; we can, and no doubt shall, greatly improve the application of those with which we are acquainted. What are called inventions can do no more than this, yet how much every day is being done by new machines and instruments.

The telescope extended our vision to distant worlds. The spectroscope has far outstripped that instrument, by extending our powers of analysis to regions as remote.

Postal deliveries were and are great and able organizations, but what are they to the telegraph?

Need we try to extend our vision into futurity farther? Our present knowledge, compared to what is unknown even in physics, is infinitesimal. We may never discover a new force—yet, who can tell?

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The last issue of the "Transactions" contains papers and discussions of the Annual Convention not before published.

On Pumping Engines by W. M. Roberts, D. M. Greene and J. H. Harlow;—On Compound Engines by J. W. Hill;—On Rails by A. L. Holley, W. Metcalf and W. W. Evans;—On Railway Signals, C. H. Fisher, J. D. Steele, W. P. Shinn and C. Paine;—On Rapid Transit in large cities;—by R. H. Buel, C. H. Fisher, J. D. Steele and W. H. Searles.

The present issue contains also a detailed account of the failure of the Brainerd Bridge, with suggestions as to the cause.

IRON AND STEEL NOTES.

Use of Rail Ends in Blast Furnaces.—Heyrowsky says that there are different methods for using rail ends in the Bessemer process, and that it is acknowledged that 20 to 25 per cent. can be introduced into the Bessemer retort without any objection. Another use has lately been tried with success at the Zeltweg blast furnace, and as Zeltweg possesses a large balance of rail ends this work is very important. The production of the furnace heretofore has been 4,600 cwt. of grey Bessemer pig per week; now it is 5,400 cwt. This difference of 800 cwt. corresponds exactly to the quantity of rail ends used. In like manner, instead of rail ends, grey and even white cast iron could be used without diminishing the economical results.—*Mining Journal.*

Remarkably Large Yield of Pig Iron by a Charcoal Furnace.—From a recent number of the Marquette Mining Journal we take the following statement of the work done by Bay furnace, No. 2, at Onota, Michigan, during the month of August last: Number of gross tons of pig iron made, 1,109¼; average make per day, 35.78 tons; highest daily yield, Aug. 20th, 41¼ tons; lowest daily yield, Aug. 7th, 31 tons; yield on the first day of the month, 35 tons; yield on the last day of the month, 36 tons; average yield of the ore, 60.31

per cent.; number of bushels of charcoal used to the ton of iron 101.98; total number of charges in the month, 3,770; total number of pounds of ore charged, 4,120,550; total number of bushels of charcoal used, 113,100. The iron was of the following grades: No. 1, 915¼ tons; No. 2, 185¼ tons, and No. 3, 8¾ tons: total, 1,109¼ gross tons. During the seven days beginning on the 19th and ending on the 25th, 276½ gross tons were made, which is believed to be the largest week's make yet attained by a charcoal furnace. This furnace is 45 feet high, and 9½ feet across the bosh. H. S. Pickands is Superintendent.—*Bulletin.*

REVOLUTION IN THE PRODUCTION AND TREATMENT OF IRON AND STEEL.—One of the most important patents which have ever been granted for the production of iron and steel will be found, says *Capital and Labor*, in that recently granted to Messrs. Samuel R. Smyth and Joseph Simpson, of No. 58 Fountain-street, Manchester. This patent commences with an exhaust vacuum furnace, and its operations extend to the manufacture of the finest productions in iron and steel. It is, however, so complete in its character that portions can be applied to existing blast furnaces, Bessemer convertors, or Siemens' furnaces. Masses of metal of twenty-five tons in weight can be treated at one time in the patentees' patent metal receiver, which forms an important feature in the invention. In it the molten metal can be purified and refined into any quality of iron, or it may be converted into steel. The cost of producing iron or steel of any quality by means of this patent process is enormously reduced. By the use of the patentees' comparatively inexpensive exhaust vacuum furnace the metal can be smelted without the necessity of providing blast engines, and it is never allowed to cool from that point until it has been manipulated into a finished production. In the manufacture of steel the purifying process (which only occupies a few minutes) enables steel to be produced from Cleveland, Lincolnshire, or Northamptonshire iron, or even from cinder pig, because the objectionable metalloids in the iron are either removed or rendered quite innocuous by the use of the compounds applied by the patentees in their apparatus. The iron being thus purified and refined, steel can be produced therefrom, by their process, without the use of spiegeleisen, In applying the process to Bessemer convertors or to Siemens' furnaces it may, however, be necessary to use a small amount of spiegel. In working this invention throughout it is a notable feature that solid fuel only comes once into contact with the metal. The gases from the coal are stored in a gasholder, and, along with those evolved in the vacuum smelting furnace, they are used in heating the furnaces for the further manipulation of the metal. By this means all the combustible properties in the coal are made use of, and after the gases have supplied all the carbonic oxyde necessary for completing the further stages of production. It is, lastly, used for raising the steam required in the boilers on the premises. By this means the consumption of fuel is reduced to the lowest minimum possible. By the patentees' method of treatment any weight of charge of metal can be purified and refined at once, and converted into steel if desired. The metal can also be held in its molten state in the patent metal receiver for any length of time which may be desired, without any waste of material, inasmuch as the metal can be oxydized or deoxydized, carbonized or de-carbonized in the metal receiver any number of times at the will of the manipulator. By this process also a plate, casting, or forging of any weight can be produced without any laminations, because in the metal receiver every atom of the metal will be of perfect evenness of quality, ductility, and density. This important invention is the result of years of careful examination and study, and the practical results which have been obtained by the application of the invention to adequate quantities of metal are such as to justify even more sanguine statements that are made herein.

MECHANICAL AIDS TO PUDDLING.—We note that ironmasters, who are not experimenting with rotary furnaces, are still casting about for a means of puddling their iron with as little manual labor as is practicable. The difficulties arising out of the want of enough puddlers sufficiently skilled to do their work properly, is driving the finished iron trade in most parts of the kingdom to seek mechanical aid, which they would otherwise not be anxious about. When men have once set up a plan, there is a pardonable reluctance to interfere with it, so long as it can be made to serve the purpose for which it was originally designed. Single-hand puddling furnaces were well enough when the demand for iron was less than now, or when men were more abundant in proportion to the demand; but now that the aggregate of the requirements of the iron-consuming world is vast, and puddlers are scarce, it becomes a necessity that a method of making finished iron in its early stages should be adopted by which a larger quantity than heretofore may be got out in the same time. Moreover, such is now the competition in the manufacture of iron, both at home and abroad, that rigid economy must be enforced. Where, therefore, ironmasters are not prepared to adopt revolving machinery, they are seeking out and adopting the best form of double furnace, worked in part by machinery, and possessing a heating chamber for warming the pig iron before it is thrown into the puddling furnace. One such furnace is known in Yorkshire as the "Joe Pickles" furnace—Mr. Pickles having been a millwright in the service of the Kirkstall Iron Company, by whom the furnace is made. There is nothing remarkably striking about it, but practical men are giving increased attention to it, and it is now being adopted outside Yorkshire. The furnace has an opening on each side, so that two men can be simultaneously employed upon it. In a double furnace of this description the back wall, with all its cost of fettling and frequent repairing, is dispensed with, and by reducing the area to be heated there is economy in the

consumption of fuel. The pigs are heated in a chamber on each side of the flue. The puddling machine consists of a frame fastened to the outer plates of the furnace. Upon this frame is fixed a small steam engine, which is arranged so as to move a beam up and down. From each end of this beam a crank is worked, having at its proximity a forked swivel, and in this the rabble or tool is fixed. The vertical movement of the beam gives a horizontal motion to one end of the crank to which the tool is attached, so that instead of the puddler or underhand having to work the iron while it is in a fluid state the machine does it, and all the workmen have to do is to change the rabble when it becomes too hot, and replace it with a cold one. By lifting it out of the swivel fork, this is done without stopping the machine. The arrangement is such that the tool working on one side of the furnace cannot come into contact with the tool working on the opposite side, for as the one is going into the furnace on one side the other is making its outward stroke, and while one is working at the fire end of the furnace the other is work-at the fire-bridge end. By an ingenious contrivance the machine causes the tool to work four strokes in each jamb before it returns on its journey across the furnace. The advantage of this will be seen when it is considered that the tool must pass over the middle of the furnace twice to reach alternately each jamb once. The furnace has water boshes around it to prevent the fettling from working out so rapidly as under the old arrangement of the single furnace. Messrs. E. P. & W. Baldwin, who have finished ironworks at Stourport, and Dudley, and Wolverhampton, are those who have most recently adopted the "Joe Pickles" furnace we have described.—*Engineer.*

RAILWAY NOTES.

MANUFACTURE OF STEEL IN FRANCE.—France, which at one time was reputed incapable of making steel, has made it at the following rates for the last twelve years :—In 1863, 1800 tons ; 1864, 6700 ; 1865, 9700 ; 1866, 10,800 ; 1867, 19,900 ; 1868, 42,600 ; 1869, 52,400 ; 1870, 90,000 ; 1871, 110,000 ; 1872, 138,500 ; 1873, 167,000 ; 1874, 217,000 tons. This extraordinary development of French metallurgy is encouraging to those interested in French industry.

AN experiment is being made with wooden rails on a portion of the Muncy Creek Railroad, an unfinished line of forty miles, in Lycoming County, Pa. U.S. Mr. H. R. Mehrling, the superintendent, has recently had 700 ft. of track laid on a curve just beyond Muncy Creek, and it has been found to answer the purpose much better than was anticipated. The rails are of sugar maple, 7 in. by 4 in., and about 12ft. in length. The ties are laid down in the ordinary way, notched, and the rails let into them about 4 in. They are then keyed firmly with wooden wedges driven on the sides, which makes the track very solid and firm. The locomotive and heavy cars have been passed over this experimental track at different rates of speed, and it has been found to work admirably, and give every assurance of success. The cost of laying wooden rails, manufactured out of this hard material—that becomes almost as solid as bone when seasoned—is 450 dols. per mile. Iron costs 4000 dols. per mile. No iron spikes are required, as the rails are secured with wooden wedges, and the cost of track-laying is about the same as putting down iron. These wooden tracks have been tried at different places in the United States, and invariably been found to work well. The highest rate of speed for locomotives to pass over them with safety has been fixed at sixteen miles per hour, but even if this rate were reduced to twelve or to ten miles, the saving in expense would more than compensate for the reduction in speed. It has also been shown by experiment that these wooden rails will last, ordinarily, from three to four years, which is another important item to be taken in consideration.

A BRILLIANT experiment in railway warfare has been conducted by Major-General Sir Charles Reid at Meean Meer. The *Pioneer of India* says its object was to test how guns and troops could be conveyed to or from any point of a railway line, independently of railway platforms and the usual accessories for the loading of heavy material. The General's method, described in a Calcutta contemporary, was as follows :—Doors, constructed to swing downwards, were opened in the front and rear of each wagon of a railway train. With all its doors down, the train became a long continuous platform, with high sides. At either end of this train was a low truck containing a pair of iron girders which could be readily run out, covered with planks, and converted into a sloping platform. Accordingly, at daybreak, half a battery of horse artillery was marched to the spot. The order was given to lower the doors and girders. The horses were brought in at one end of the train, and placed head to head, in their separate trucks, while the guns and the carriages were run up on the girders at the other ; the artillerymen were distributed in second class carriages ; finally, the girders and doors were pulled up, the engine was attached, and away went the half-battery on its expedition, in 36 minutes after its arrival on the spot. After a run of some minutes the train stopped at a place where there was a raised embankment, about half a mile from a level crossing. The doors and platforms were thrown down ; the horses went out at one end, and the Armstrong guns at another, and in less time than seven minutes the first gun opened fire from the embankment. It took only 45 minutes from the time the train stopped to limber the guns, each of which was pulled by six horses, and to reach the level crossing in full force and complete order.

ENGINEERING STRUCTURES.

SEVERAL civil engineers, engaged with the surveys for a water conduit from Touja to Bougie, have made a very interesting and important discovery. A mountain which was

situated in the proposed line of the conduit was to be tunneled for a length of 500 yards; and in searching for the most suitable place the engineer discovered an ancient tunnel 6 ft. 8 in. in height, and 19 ft. 7 in. in circumference. It is supposed that this is the same tunnel mentioned in an epigraph found at Lambeoc, according to which the tunnel was built in the reign of Antoninus Pius, the plans being prepared by a veteran of the Third Legion, named Nonius Datus. Finding works like this after a time of 2000 years, we cannot but be greatly astonished at the power, energy, and genius of a nation which produced, with the limited means available at those times, such gigantic structures.

WONDERFUL ENGINEERING.—Any one desiring to obtain any idea of the stupendous accomplishments of railroad engineering should spend a few days in Tehachape Pass, investigating the operations of the Southern Pacific Railroad Company. About twenty miles of that road is a succession of cuts, fills and tunnels. Within this distance there are thirteen tunnels, ranging from 1100 feet to a few yards in length. For the greater portion of the way the road bed is cut through solid granite. The elevation is so great from the present terminus of the road, at Caliente, to Tehachape Valley, that the first mile and a half out of Caliente is attained by laying down eight miles of track. Higher up in the pass the road runs through a tunnel, encircles the hill, and passes a few feet above the tunnel. After completely encircling the hill, and going half around again, the track doubles on itself like a closely pursued hare, and after running several miles in the opposite direction, strikes up the canon. This circling and doubling is for grade. Once the track crosses the pass, and this involves the building of a long and very high bridge. We doubt if a more difficult and expensive piece of engineering was encountered in the building of the Central Pacific over the Sierras than that with which the Southern Pacific is now struggling in Tehachape Pass. Another tremendous piece of work is the San Fernando tunnel, which, when completed, will be over a mile and a half in length, and in places over 1000 feet beneath the surface. Yet the company will accomplish this great work, and run cars through from San Francisco to Los Angeles by the first of next July. All the force that can be used is kept at work on the San Fernando tunnel. In the Tehachape Pass 5000 men are employed, and the force is being increased at the rate of 1000 Chinamen per week.—*Los Angeles (Cal.) Herald.*

ORDNANCE AND NAVAL.

THE work with the 81-ton gun, if it had been less important than others, has been of a more interesting character than any of its predecessors. In the first place the gun had to be lifted into its carriage, and it remained to be seen if it was properly adjusted. Of this the officials entertained no doubt from the care with which every part of both gun and carriage had been made to scale. The gun was lifted just as other guns are, by rope slings passed under its arms, or trunnions, and so well had their proper position been calculated that the monster hung in an exact horizontal line evenly balanced. The work of transferring it to its place on the carriage occupied only a few minutes, and it fitted, as anticipated, with perfect accuracy everywhere. Then came the more serious task of removing it down to or towards the butts, and for this work the locomotive which waits on the Royal gun factories, and is called the "Gunner," was brought into requisition. This locomotive, though much more powerful than the little engines which run about the Royal Arsenal on the narrow gauge, is not half the size of the ordinary railway locomotives, and doubts had been expressed as to its being equal to the duty required of it. Indeed, when it was first set to pull the great Juggernaut-like car along the railroad it was utterly unable to move it. Again and again the engine made the attempt, occasionally moving the wheels an inch or two, but more often pulling up dead, or snapping in twain the great hawsers by which it was attached. The character of the railway line had much to do with this failure; it was laid down a good many years ago for very different work. It is rough and irregular, and, moreover, it rises at first on a slight incline. By the help of lifting jacks, handspikes, and a rope attached to a stationary engine in one of the workshops, the carriage was coaxed on for about a hundred yards, but the 120 tons of dead weight resting upon its twelve wheels all packed close together was slow to move, and it was feared that the attempt must be given up for the day, or some other expedient adopted. It occurred, however, to some one to harness on a couple of the small locomotives in front of their larger brother, as the narrow and broad gauge lines run together. This proved the solution of the difficulty, for the three engines moved the burden quite easily, to the surprise of almost everybody, the additional power lent by the little engines being to all appearance ridiculously small. A stoppage, however, took place shortly before reaching the canal which separates the practice ground from the rest of the arsenal, and it was decided to defer crossing the bridge until to-day. Beyond the canal is the worst part of the line, as it runs along an embankment down a steep incline, which has on one occasion given way.

TORPEDO BOAT FOR THE AUSTRIAN GOVERNMENT.—MESSRS. J. THORNYCROFT, of Chiswick, have just completed a steam torpedo launch for the Austro-Hungarian Government. A trial of this boat took place on Saturday last, the 11th inst., on the Thames below London Bridge. At the trial trip there were on board, besides the builders of the vessels: Baron Spaun, Naval Attaché, Austro-Hungarian Embassy; the Vicomte de la Jour du Pin, Naval Attaché, French Embassy; and Mr. Schneider, Chief Engineer, Austrian Navy. A start was made a little below the Thames Ironworks at eleven minutes past twelve, and

the hour's run finished at Lower Hope Reach, below Gravesend, at eleven minutes past one o'clock. During the run the number of revolutions was taken by Mr. Schneider and Mr. Walker, chief draughtsman at Messrs. John I. Thornycroft and Company's, and was found to be exactly 24,700. The vessel was then run up to Long Reach, and run six times over the measured knot there, when the number of revolutions of the engines required to do one knot was found to be 1357. The number of revolutions done during the hour (24,700), divided by the number required to do one knot (1357), gave the number of knots done in the hour as 18,202, a result which is certainly most satisfactory.

On the way up to London the vessel was run past a small schooner at a speed of ten knots, and a dummy torpedo was launched against her side. The torpedo struck the schooner amidships at about 6 ft. or 7 ft. below the water level, and had it been filled with its charge of dynamite (25 lb.), the schooner would undoubtedly have gone to the bottom. The torpedo gear on this vessel consists of two poles 38 ft. long, one on either side, and so arranged that an attack may be made directly ahead of the boat, in which case the boat must be stopped and backed off her enemy immediately after the explosion; or on the broadside, when the boat may be kept going ahead all the time, and so saving the time which would be otherwise lost in stopping and backing. The dimensions of the torpedo launch are:—Length, 67 ft.; beam, 8 ft. 6 in.; and the speed guaranteed by the builders was fifteen knots.—*Engineer.*

BOOK NOTICES

IVESON'S HORSE POWER DIAGRAM. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $4.25.

This is a folding chart to facilitate calculations of horse power of engines, when the ordinary data are given.

The results are found by line illustrations on finely engraved charts.

CLIMATE AND TIME IN THEIR GEOLOGICAL RELATIONS. By JAMES CROLL. New York: D. Appleton & Co. Price $2.50.

Mr. Croll has set forth his views at various times in the *Philosophical Magazine* and other British journals.

He is a vigorous writer, and has earned a right to respectful attention by his varied labors as a geologist.

The principal topic of the present work is the change in temperature of the earth's surface during geological ages, the evidence of which we find in the coal and drift formations.

The illustrations, consisting largely of colored charts, are very good.

HAND BOOK FOR CHARCOAL BURNERS. By G. SVEDELIUS, translated from the Swedish by R. B. ANDERSON, A. M. New York: John Wiley & Son. Price $1.50.

We presume this treatise may be considered of some value in some part of this country, though we don't exactly know where. Judging from the preface, the chief reason for the original publication in Sweden was a Government Prize of six hundred and fifty-six rixdollars.

The author certainly made a good deal of one of the simplest operations in the world. The minuteness with which the details of the manual labor is described is equaled by nothing we know of except instructions for crocheting and needlework.

Charcoal makers, who desire to know how elaborate a process they are engaged in, should possess themselves of this work.

A MANUAL OF METALLURGY. By WM. HENRY GREENWOOD, F.C.S. Volume 2. New York: G. P. Putnam's Sons. For sale by Van Nostrand. Price $1.50.

The subjects treated in this volume are the extraction severally of Copper, Lead, Zinc, Mercury, Silver, Gold, Nickel, Cobalt, and Aluminum from their respective ores.

The work is systematic, giving the natural history of the different native compounds of these metals, and also their chemical constitution.

The reader is cautioned in the preface not to expect such a description of the details of metallurgical operations as only the larger works can contain; the author only attempts to give such explanations as are generally received of the scientific principles upon which the processes are based. This he seems to have satisfactorily accomplished.

PROBLEMS IN STONE CUTTING. By S. EDWARD WARREN, C.E. New York: John Wiley & Son

Prof. Warren's works are so well known, that we need not enlarge upon their general excellence. From such inspection as we have been able to make of this work, we should say it was equal to the best of the professor's previous books.

We know of nothing so acceptable just now as this book. Having been called upon during the last season to recommend such a book as a supplement to a course in descriptive geometry, we were obliged to recommend parts of two or three expensive works as the only way of fulfilling the requirements. This new work of Prof. Warren's would have answered completely to the demand.

With his usual precision of classification, the author divides his problems into four classes; viz:

I. Plane-sided structures.
II. Structures containing developable surfaces.
III Structures containing warped surfaces.
IV. Structures containing double curved surfaces.

Tin folding plates illustrate the work, containing seventy-three separate figures.

THE MECHANICAL ENGINEER: HIS PREPARATION AND HIS WORK. An address to the graduating class of Stevens' Institute. By R. H. THURSTON, A. M. C. E. New York: D. Van Nostrand. Price 50 cts.

It is well that this able address is put in a

form to reach beyond the circle for whom alone it was originally prepared. At the request of the hearers, it was published in neat pamphlet form.

The address may be read with profit by young and old of other professions than that of mechanical engineer.

The professor first details the nature of the studies pursued, and sets forth the advantages of the culture derived from each, then gives some exceedingly practical advice in regard to the use of the acquired talents in their professional career.

It is not a farewell speech of the ordinary academy or college type, but widely different in many respects, and naturally so, inasmuch as the graduates to whom it was addressed had presumably adopted a profession, and were entitled to advice regarding its duties. It is certain that no one was better fitted to advise them than their talented professor of mechanical engineering.

THE PAST AND FUTURE OF GEOLOGY. By JOSEPH PRESTWICH, F.R.S., F.G.S. (An inaugural address.) London: McMillan & Co. For sale by D. Van Nostrand. Price $1.00.

From so eminent a source, an essay on the subject of Geological discovery is exceedingly valuable. Of course, the question of internal heat receives a large share of attention.

Several well executed diagrams, illustrating the distribution in time, of organic life, adorn the book and convey a surprising amount of information at a glance.

SEXTON'S POCKET-BOOK FOR BOILER-MAKERS AND STEAM USERS. By M. J. SEXTON. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $2.00.

This is substantially a table book of weights and dimensions of parts of a boiler. But brief treatises on the care and management of boilers are interpolated between the separate tables.

The book is neatly made, after the manner of the smaller table-books—opening lengthwise—is pretty well illustrated with wood-cuts, and moreover is furnished with blank leaves at different places throughout the book—a plan worth following in all similar works.

ON THE STRENGTH OF CEMENT. By JOHN GRANT, C.E. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $4.25.

This work gives detailed description of experiments upon the strength of cements; but chiefly on Portland cement, used in the southern main drainage works of London. The volume is a reprint of papers read before the Institution of Civil Engineers on two separate occasions: December, 1865, and April, 1871.

Besides the results of many experiments carefully tabulated, the plates afford valuable information to engineers respecting the construction of sewers of various sizes.

HOMES AND HOW TO MAKE THEM—ILLUSTRATED HOMES. By C. C. GARDNER. Boston: James R. Osgood & Co. For sale by D. Van Nostrand. Price $3.00.

These unique volumes ought to be widely read. They are designed primarily for those who are about to build, or who have friends soliciting advice about building houses; but they may be read with pleasure and profit by any who delight in lively pictures of home life amid people who are altogether human, mostly witty, and in every way agreeable to meet as the author presents them.

They are worth careful reading as samples of successful presentation of a semi-technical subject in a delightful way.

THE JOURNAL OF THE IRON AND STEEL INSTITUTE. Part 1. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $3.75.

Among the papers of this new volume, the more important are:

The Ores of Iron in their Geological Relations. By Warrington Smith, F.R.S.

Notes of a visit to Coal and Iron Works of the United States. By I. Lowthian Bell, F.R.S.

The Sum of Heat utilized in Smelting Cleveland Ironstone. (Same author.)

The Manufacture of Bessemer Steel in Belgium. By M. Julien Deby.

Reports of Iron and Steel Industries in the United Kingdom and in Foreign Countries.

THE WORKS OF E. VERDET: Cours de Physiquie. 2 vols. Legons D'Optique Physique. 2 vols. Conferences de Physique. 2 vols. Theorie Mecanique de Chaleur. 2 vols. Notes et Memoires. 1 vol. Paris: Victor Masson.

Nothing in the way of wood-cut illustration or typography can be finer than is exhibited in these works of Verdet.

The volumes average something over 500 pages each. To illustrate the Cours de Physique alone there are 516 wood-cuts.

In Physical Optics this work is the most extensive with which we are acquainted. All are standard works.

A NEW METHOD OF OBTAINING THE DIFFERENTIALS OF FUNCTIONS. By Prof. J. MINOT RICE, of United States Navy, and Prof. W. WOOLSEY JOHNSON, of St. John's College. Revised edition. New York: D. Van Nostrand. Price 50 cts.

The authors of this little essay advocate a return to the method of *fluxions*, which has been almost abandoned by modern instructors.

The method of presenting the subject is certainly clear, and to the mathematical student attractive. Whether the beginner finds difficulty in accepting the doctrine of limits or not, he will certainly reap benefit from a study of this little treatise.

AN ELEMENTARY TREATISE ON STEAM AND THE STEAM ENGINE. By D. KINNEAR CLARK, C. E. London: Lockwood & Co. 1875. For sale by D. Van Nostrand. Price $1.40.

We have here, recast, one of the series of practical works, presenting in a cheap and generally reliable form the elements and principles of science and art, and known as Weale's. The present work is adapted from Mr. John Sewell's elementary treatise on steam, the portions of that treatise, useful in its day, which time and discovery have rendered obso-

lete, being replaced by matter more directly interesting to the steam engineer. Other subjects, such as the mechanical theory of heat, unknown at the first publication of the work, are introduced for the first time, as well as the more important of the numerous improvements that the steam engine has received in the interval. The historical notice of steam and the steam engine, by Mr. Sewell, is retained unaltered, although susceptible of considerable improvement. At all events, such an obvious blunder as the representation of the goddess Isis as a male divinity, and the change of the termination of her name to suit the change of sex, might have been corrected. In the practical portion every essential part of the subject is treated of competently and in a popular style; while there are also given numerous and useful tables illustrating the capacities of boilers, and the properties of fuel and steam.

ENGINEERING PAPERS. By C. GRAHAM SMITH, Stud. Inst. C. E. Spon, London. 1875. For sale by D. Van Nostrand. Price $3.00.

This little work is a reprint of three papers on mortar, practical ironwork, and retaining walls. The first two were read before the Institute of Civil Engineers, and each obtained a Miller prize. The third was read before the Edinburgh and Leith Engineers' Society. We are pleased to see these papers put together in a convenient and accessible form, for they are very practical in their character, and contain a good deal of useful information. The paper on mortar is probably the best available treatise in the English language on the subject. That on practical ironwork is valuable, because it deals with the subject in a way hardly ever employed by other authors. Mr. Smith says little or nothing about strains, but he gives numerous practical hints about the way iron structures should be designed and put together; and in a species of appendix to the paper he very properly calls attention to a fact too often overlooked—namely, that what are termed "fancy" sizes and sections of iron always command a fancy price. The designer should always endeavor to work with marketable materials; but the student will search most books in vain before he can discover what sizes of iron are and what are not easily to be had at ordinary prices. The paper on retaining walls is simply and clearly written, but it does not contain much that is very novel; indeed, so much has been written about retaining walls, that it is impossible to say anything new on the subject. We can recommend Mr. Smith's little book, especially to the younger members of the profession.—*Engineering*.

DESIGNING VALVE GEARING. By E. J. COWLING WELCH, M. I. M. E. E. & F. N. Spon. For sale by D. Van Nostrand. Price $2.00.

This is a most useful text book, and something of the kind has long been a desideratum among draughtsmen and engineers. Valve gearing constitutes a rather difficult and perplexing problem, and the solution offered by scientific men in formulated results, is to the ordinary engineer only more perplexing still. Mr. Welch has conferred on the profession a great boon in this little book, in which he elucidates all the problems connected with the subject in as simple a geometrical manner as possible. In his opening chapter he gives the geometrical basis, viz., the 31st Proposition in the 3d Book of Euclid, on which his diagrammatic investigation depend. He then treats of the easy method in which the relative travel of crank, eccentric tumbler and slide valve may at any moment of the stroke be compared, and afterwards proceeds to treat of lap and lead, and adjustment of ordinary slide and expansion valves, for any ratio of cut-off. His further chapters on variable expansion valves, and on Stephenson's, Gooch's and Allan's link motion, are admirable, and invaluable to the engineer and draughtsman, who would wish to rise superior to the ignoble, but too frequent plan of valve designing by trial and model. There are but one or two little points in this most admirable text-book which we could wish altered for the better. The diagrams are excellent, and sufficiently numerous, but the matter is too heavily printed without break for convenient and comprehensive reading. The system of paragraphs, and special results being placed in separate lines, render such matter of much easier perusal and comprehension. Further, the book can scarcely be read with interest for general information. It is simply a series of propositions, since there is seldom half a dozen lines without reference to the diagrams. The diagrams are frequently not on the page in which they are being constantly referred to, and thus destroy all chance of consecutive reading. The book must be laboriously studied, like a book of geometry, but, nevertheless, is so well worth that study that we most heartily recommend it to all who may have valve gearing to design.

THE PRESENT PRACTICE OF SINKING AND BORING WELLS, &c. By ERNEST SPON. London: E. and F. Spon. 1875. For sale by D. Van Nostrand. Price $3.00.

When the pollution of our rivers by manufacturing processes and the sewerage of large towns has risen to such a pitch that legislative measures are necessary to prevent widespread epidemical disease, it seems high time that some steps should be taken to obtain the supply of water for drinking purposes from some less feculent source. And it is not only in populous and manufacturing districts that such a precaution is necessary. In agricultural districts most of the supply is drawn from surface drainage or shallow wells, both becoming more and more unsafe owing to the increasing practice of dressing pasture as well as arable land with manure to an extent unknown but a few years ago. Under these circumstances it is well that deep in the bowels of the earth, especially in those countries where a wholesome supply is most difficult to obtain at or near the surface, there exist vast reservoirs of the pure element, which the improved engineering appliances of these days enable us to reach, and which, as in Liverpool, South London and elsewhere, have already been to a considerable extent utilized. To teach us to tap these stores in the best and

most economical way is the object of Mr. Spon's book. Suitability of site for a deep well depends mainly upon three considerations. First, there is the capacity and lie of the water-bearing strata, next, the extent of its outcrop, and, third, the amount of rainfall over the area of the outcrop. The presence and position of faults in the strata is another important element. Springs depend upon the rainfall, and that they sometimes appear independent of it is owing to the extent of the subterraneous accumulations which they drain. In deep wells where the water is collected from a surface much above the level of the well, the water, when tapped, especially at first, often rises with great force and to a considerable height. The secondary and tertiary formations, the last especially, from the alternations it presents of loose, sandy permeable strata with impervious rocks and clay, are the most suitable for deep well-boring. Some of the primary formations also are water bearing; but from the more general presence in them of bituminous, or other mineral impurities, they are less suitabe for water supply. The chalk —a secondary formation—is the great water-bearing stratum for the larger portion of the south of England. The greensand underneath it also contains vast supplies. In the midlands and northern counties again, the Permian and triassic formations yield immense quantities of water, and supply Coventry, Birmingham, and other large towns, copiously. Mr. Spon gives formulæ by which to estimate the probable supply in each case, furnishing also much varied and useful information applicable to numerous localities, which he follows up with an exhaustive practical exposition of the art and mystery of well-sinking, profusely illustrated, but through which it is difficult to follow him without the aid of his diagrams. We notice, however, no allusion to any of the numerous forms of diamond drill which have become so indispensable in all boring operations.

Some interesting information is given regarding the districts already supplied by wells in the strata above referred to. From the lower Permian sandstone large quantities of water are pumped for the use of Sunderland and many neighboring towns and villages. This supply, calculated to reach five millions of gallons a day, is obtained from an area of fifty square miles overlying the coal measures. Coventry is supplied with 750,000 gallons a day from two bore-holes driven from the bottom of the reservoir into the new red sandstone, the water rising at the rate of 700 gallons a minute. The wells of the Tranmere, Birkenhead and Wirral Waterworks yield together about four millions of gallons a day, drawn from the trias. Two million gallons of the water used in Birmingham comes from the new red sandstone. Crewe, Leamington, and Liverpool are supplied from the same formation. In 1850 the yield of one of the bore-holes in the last-named town was nearly a million gallons in the twenty-four hours. The Goldstone wells, from which Brighton is supplied, are in the chalk, and each yields about 3,000,000 gallons daily.

TRAITE THEORIQUE ET PRACTIQUE DE LA FABRICATION DU FER ET DE L'ACIER, ACCOMPAGNE DUIN EXPOSE DES AMELIORATIONS DONT ELLE EST SUSCEPTIBLE PRINCIPALEMENT EN BELGIQUE PAR B. VALERIUS. Deuxieme edition originale Francaise. Royal 8vo, paper, with folio Atlas plates. Paris, 1875. For sale by D. Van Nostrand. Price $30.00.

This is the work of Prof. Benoit Valerius, who died May 30, 1873, now published from his MSS, and with considerable additions, by his brother, Prof. H. Valerius, of the University of Ghent. The text of this elaborate work forms a volume of 852 pages, royal 8vo. The plates are in portfolio, large quarto, and 35 in number, and are the finest as well as the most extensive series of drawings upon the subject that have ever been issued. Those covering the subject of roll turning are particularly noticeable in their elaborate character and fineness of execution.

APPLIED SCIENCE. Part 1. Geometry on Paper. Part 2. Solidity, Weight and Pressure. By EDWARD SANG. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price each $1.25.

These two books are smaller than might be expected from their titles, but small as they are, they are quite disproportionate, on the side of bulk, to the amount of valuable information they contain.

Part 1 is a collection of examples in Plane Geometry, in which the pupil is advised to use very rude instruments; the diagrams suggest home-made ones.

Part 2 makes similar suggestions in regard to Solid Geometry, but adds chapters on Cube Root, Strains and the Steel Yard. The appearance of these apparent incongruities is explained by the author's opinion expressed in the preface, that the study of practical geometry must lead us to examine all the physical properties of matter which can influence our measurements or aid us in conducting them.

A TREATISE ON THE ORIGIN, PROPER PREVENTION, AND CURE OF DRY ROT IN TIMBER. By THOMAS ALLEN BRITTON. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $3.00.

Although the chief title of the book limits it to a consideration of dry rot in timber, the author has by no means confined himself to a consideration of this subject, but has devoted the greater portion of the volume to the descriptions of various established processes of seasoning and preserving timber and wooden structures, of the destruction of this material in hot climates, and of the decay of furniture, wood-carvings, &c. The first chapters, it is true, after the introductory remarks on the nature and properties of timber, deal with the question of dry rot, and besides describing its general characteristics and results, quote many authorities and give several illustrations bearing on the subject. Taken altogether the information is scarcely so complete as that contained in the article published by us last week (see *ante* page 151), and based upon the excellent treatise of M. Bourseul. After some consideration on the subject of felling and cutting

timber, the author proceeds with lengthy descriptions of various seasoning processes. Amongst them are Davison and Symington's desiccation method, Bethell's drying stoves, introduced between 1848 and 1863, Langton's patent for the extraction of sap, Kyan's bichloride of mercury process, the creosote treatment of Mr. John Bethell, Boucherie's sulphate of copper method, and many others tried in this country and abroad.

Coming back then to a subject more apropos to the title of the book, the author gives us a chapter "on the means of preventing dry rot in modern houses, and the causes of their decay." And under this heading we come suddenly to a receipt for killing rats, though what connection there is between these animals and dry rot, we do not at present perceive. Make a hole for the rats to come up, if they do not make one for themselves, mix a nauseous compound into pills and place it on the floor, with a number of saucers filled with water. The confiding nature of the rats will induce them to eat the compound before alluded to, which will make them so thirsty that they will drink till, like the sculptor in the conundrum, they "make faces and busts." "They can be buried in the morning," adds thoughtful Mr. Britton. To return to dry rot. Ventilation, pitching, and charring, are the best preventives fully pointed out by the author, who then quits his subject to dwell upon the æsthetics of house painting, but returns to it again finally and briefly as follows: "One cause of the decay of modern buildings and frequent cases of dry rot, is owing to the employment of bad builders." We are in error: for in closing this volume we find one more reference to the subject.

"In conclusion, we can only summarise our remarks on the cause of dry rot by saying 'season and ventilate' in every case. As to to the cure, that is not so easy to deal with. If the reader has ever had a decayed tooth aching, a friend has probably said, 'Have it out;' and we say, whenever there is a piece of timber decayed in a building which can be removed, 'Have it out and stop up with new,' and in so advising we are merely following the advice to be found *in a good old volume which has never yet been equaled.*" Here follow some verses from Leviticus. The italics are our own. The above extract will show that Mr. Britton, besides knowing all about dry rot in timber, has quite a happy way of communicating his knowledge. The publishers have done their part well in the preparatian of this volume.—*Engineering.*

MISCELLANEOUS.

DEEP SILVER MINE.—In Pribram, Bohemi, the Adalbert Pit, sunk in 1779, has reached in its present adit in the 1000-metre shaft the depth of 472.128 metres below the level of the Adriatic Sea.

STEEL RAILS IN ITALY.—The line from Rome to Ceprano, half-way from Rome to Naples, has been relaid with steel rails, the first result of which change has been to permit a higher speed of travel, resulting in a total saving of time on the journey of an hour and a-half.

THE NEW RUSSIAN GUN.—The great Russian cannon, lately built at the works at Obouk-owsky, has cost £13,000, and weighs 40 tons. It is a breech-loader, entirely in crucible steel, 20 feet 6 inches long; its largest ring is 57¼ inches in diameter, and the tube has thirty-six grooves.

LIGHT HYDRAULIC MOTOR.—An improved hydraulic motor for light machinery—a Swiss invention—consists of an oscillating engine within a water-tight casing, into which the water enters at one side and leaves at the other. The oscillating cylinder, driven by the water, swings in bearings, suitable entrance and exit ports of the bearing permuting alternately the entrance and discharge of water from the cylinder. The piston rod is pivoted to a crank disk of the driving shaft, and the power is transmitted by a friction cone and belting, and can be run at different speeds. The regulating air chamber secures uniformity of motion under various pressures. The casing is attached by screws at any suitable point near the machine to be operated, and the water can be conveyed by rubber pipes. No oiling is necessary, as the apparatus works entirely in water. It is said to be capable of from 120 to 500 revolutions per minute, with an average water consumption of 40 gallons.

INCRUSTATION OF BOILERS.—This important subject has occupied the attention of the Paris Academy of Sciences. M. Lesueur, a telegraph inspector, sent a communication to the Academy setting forth the efficacy of zinc in protecting boilers from incrustation. M. Lesueur declares that in many instances the effect has been found excellent, the deposit being little and easily removed. It was asserted, in opposition, that in many cases, also, the zinc had failed entirely to produce the effect desired, and a quotation from Professor Knapp's "Chemical Technology" was read, in which the author states that, to the time he wrote, the pretensions of the advocates of galvanic action seem to be unfounded. It was recommended that the subject be entrusted to a committee for conclusive trials. A long list was given of the various substances which had been recommended for the preservation of boilers, such as a mixture of tallow, graphite and charcoal, of tar and oil, iron filings, broken glass, saw-dust, clay, alum, and soda mixed, potatoes, molasses, coarse sugar, chicory, trimmings of skins, sal ammoniac, chloride of barium, carbonate of barytes, and chloride of zinc.

As was stated before the Academy, the problem in question is a very complex one, and it is well that all should understand that it is not likely to be solved in a general manner. There can scarcely be any universal panacea. Water differs greatly in composition, and even the same water varies from time to time, so that the only chance of success in the adoption of an anti-incrustation medium would seem to depend upon a careful analysis of the water to be used, repeated at different seasons.